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CANADIAN JOURNAL OF PSYCHOLOGY

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CLOSURE WITH NEGATIVE AFTER-IMAGES UNDER FLICKERING LIGHT[1]

CRAIG M. MOONEY
Defence Research Medical Laboratories, Toronto

WHEN closure (the recognition of familiar objects or events which are incompletely represented) is elicited with graphic presentations of the kind employed by Street (4) and Mooney (2, 3), questions arise concerning the role of time and multiple visual fixations.

Experimental resolution of such questions calls for three contrasting methods of eliciting closure: (1) where ample time is afforded for viewing the test item with opportunity for multiple visual fixations; (2) where time is brief with opportunity for but a single fixation; (3) where time is ample with opportunity for but a single fixation. The first method entails only direct presentation for unrestrained inspection. The second method is realized by tachistoscopic presentation. An adequate third method has been wanting.

It seemed possible to realize the third method through the phenomenon of negative after-images. If S stared fixedly for several seconds at a designated mid-point on the photographic negative of an object and then looked away to a gray screen, he could see the object in its positive state by virtue of the negative after-image which subsequently appeared. Preliminary trials using incomplete graphic depictions of human heads and faces (which proved unnatural and unrecognizable in their photographically negative state) indicated that closure could be effected with the negative after-images. But the following difficulties arose: several seconds elapsed before the negative after-image appeared; it tended to drift off the screen; it was not sharp and clear; it did not last long. Blinking the eyes rapidly seemed to improve the negative after-image. Accordingly, a flickering light was introduced during the induction stage. This, at a rate between two and ten cycles per second, and with a light-dark ratio of 50:50, strikingly improved the negative after-image by bringing it on instantly, making it more vivid, giving it a steady, sustained duration, and lessening its tendency to drift.

The present study was undertaken, therefore, to ascertain whether the

[1]This paper is based on a thesis submitted to McGill University in partial fulfilment of the requirements for the degree of Doctor of Philosophy. The work was done in part at McGill University, supported by a Rockefeller grant to D. O. Hebb.

CANAD. J. PSYCHOL., 1956, 10 (4).

postulated third method of eliciting closure could be satisfactorily realized through the agency of negative after-images induced under flickering light. This entailed discovering an approximately optimal flicker rate, determining that closure performance was significantly better with flicker than without, and establishing that this superiority could not be attributed to flicker, *per se*.

Method

Test Materials

The first requirement was for a type of closure item that could be presumed to be universally familiar and which lent itself to presentation by the method of negative after-images. The human head and face uniquely commended itself. From illustrated magazines photographs were selected which revealed parts of the head and the features in markedly contrasting highlights and shadows. Hand drawings were made which copied only the highlights or the shadows in solid blacks and whites. The result was a series of incomplete pictures of actual people which, when perceived, strikingly resembled their particular originals. Of 80 drawings made in this fashion, 30 were subsequently discarded as poorly drawn or ambiguous, or too easy or too difficult to see. The remainder were reproduced in both positive and negative form on 35 mm. slides. Examples of these "closure faces" are shown in Figure 1.

Apparatus

A projecting apparatus was devised. This comprised a 500-watt slide projector with a light-interrupter in front of it, driven by a variable speed motor. The light beam—and, hence, the images projected on a screen—could be flickered with a light-dark ratio of 50:50 at any desired rate up to 30 cycles per second. One ancillary attachment permitted a high-pitched musical tone to be delivered through ear-phones, in synchronism with the light. Another ancillary attachment permitted the blocking out of five out of six of the light flashes delivered through the interrupter; this feature provided tachistoscopic control so that a single exposure or a rapid succession of exposures could be made at speeds up to one thirtieth of a second.

Procedure

The standard testing situation was this: *S* sat in a dark room about five feet from a wall on which two white screens hung side by side. The projecting apparatus was concealed by a partition, so that *S*, seated on the right, was able to see only the two screens—the right one directly ahead and the left one from an angle of about 20 degrees. The size of the image projected on the left screen was 20×30 inches. A toggle switch at *S*'s right hand allowed him to signal *E* by turning on and off a small light beside the projector visible only to *E*. In the first 10 minutes of a testing session *E* told *S* how the pictures were made; that while a given picture might at first look meaningless it would suddenly organize itself into a natural picture of a real person's head or face; *E* then gave two examples and had *S* practise describing the persons; this was done by stating such applicable facts as sex, approximate age, position or orientation of the head, notable features, apparent expression; on the weight of evidence *E* could decide if *S* had made a correct closure. Before being tested with negative after-images, *S* was given practice with simple geometric designs and then one or two easy closure faces. On the left-hand screen, *S* fixated

FIGURE 1. Examples of closure faces.

a designated mid-point on the projected image for 30 seconds; on *E*'s signal "now" S switched his gaze to the middle of the right-hand screen; at the same moment the light interrupter was turned on so that S saw the negative after-image under flickering light.

For the reasons that individuals differ markedly in closure facility, that the difficulty values of the closure faces are unknown, and that a closure item cannot be used a second time with the same subject, it was desirable to base experiments on counter-balanced analysis of variance designs, using many subjects, each being tested under all experimental conditions, and using different, randomly assorted sets of test items for each condition.

Experiment I

The aim was to discover an approximately optimal flicker rate for clear induction of negative after-images.

Method

Apparatus and procedure here differed somewhat from the standard ones employed in subsequent experiments. S sat in darkness observing a translucent screen (6" × 10") in a wall, four feet away. A 35 mm. slide projector (250 watts) projected the test item onto the screen from the other side. S used an on-off switch which operated an electric timer. A practice item was a black ring on white ground with black dot in centre. A test item was two concentric black circles about a black disk on white ground with a white dot in centre. An episcotister with a light-dark ratio of 50:50, driven by a variable speed motor, interrupted the projector beam.

After due preparation and practice, S—at half-hour intervals or longer—was tested with six flicker rates, namely: 0.0, 2.5, 5.0, 10.0, 12.5, and 15.5 cycles per second. S fixated the centre of the projected test item for 30 seconds; it was then removed and the screen left dimly illuminated under steady or flickering light. S recorded time in seconds from first appearance of the negative after-image to its first disappearance. Ten Ss were used (3 adult males and 7 adult females) with the flicker rates randomly ordered for each. The experiment was repeated with 10 youths (RCAF Flight Cadets). Readings for the 10 subjects, for each of the 6 flicker rates, were treated by analysis of variance.

Results

The initial durations of the negative after-images, in seconds, are shown in Table I. An analysis of variance attributable to *subjects, flicker frequencies,* and *remainder* revealed, for the adult group, an *F* ratio at 0.01 level for *subjects,* and 0.05 level for *flicker frequencies*; for the Flight Cadets, these two ratios were at 0.01 level.

This indicated that a flicker rate between two and five cycles per second would extend the duration of the negative after-images. The data gave no information about the vividness of the after-images, although Ss testified that they seemed more vivid in this same range.

TABLE I

INITIAL DURATION (IN SECONDS) OF NEGATIVE AFTER-IMAGES INDUCED UNDER DIFFERENT FLICKER FREQUENCIES

	Adults						Youths					
	Flicker frequencies						Flicker frequencies					
Subjects	0.0	2.5	5.0	10.0	12.5	15.5	0.0	2.5	5.0	10.00	12.5	15.5
1	2.50	7.00	9.50	2.25	5.50	2.50	6.40	17.50	12.00	6.50	4.60	2.10
2	1.00	9.00	4.00	2.50	2.00	2.75	5.50	9.20	17.50	5.30	7.60	4.50
3	3.75	9.00	1.25	7.00	2.75	8.00	7.70	11.50	10.00	8.00	6.30	8.00
4	8.00	6.50	3.75	2.25	3.25	2.00	4.30	7.50	7.50	1.50	2.30	1.40
5	6.00	16.00	9.00	9.00	5.50	8.75	4.20	14.50	7.40	11.0	6.80	10.25
6	4.50	7.75	3.75	2.50	2.50	1.50	8.50	10.00	15.30	6.90	10.00	11.00
7	5.75	9.75	7.50	4.75	7.25	10.00	6.20	8.30	4.50	5.50	7.00	5.50
8	8.50	3.25	7.75	6.75	4.00	1.50	2.50	3.00	7.00	1.30	2.70	1.30
9	6.75	10.00	6.50	2.50	1.25	1.00	5.00	8.60	19.10	8.20	6.00	7.70
10	7.75	7.25	27.50	11.00	6.50	8.75	9.90	19.90	13.50	8.50	11.00	8.50
Total	54.50	85.50	80.50	50.50	40.50	46.75	60.20	110.00	113.80	62.70	64.30	60.25

Experiment II

The aims were to ascertain that closure was possible with negative after-images, to establish that flicker did not *per se* facilitate closure, and that prior inspection of the photographic negatives (prelude to induction of the negative after-images) did not confer perceptual advantage.

Method

The testing situation was the standard one already described. The test items were 48 closure faces randomly sorted into 4 groups of 12. There were four viewing conditions: direct inspection of positive items; the same, but under light flickering at three cycles per second; direct inspection of positive items following 30 seconds viewing of the negative with the gaze held on a designated mid-point; inspection of the negative after-images under light flickering at three cycles per second. Time allowed for closure was 30 seconds in all instances.

A $4 \times 4 \times 4$ factorial design was employed, accounting for the variables *item groups, viewing conditions,* and *order.* This, replicated three times, called for 48 Ss.

Subjects were 48 inmates of a boys' reformatory with a mean age of 19 years, modal school grade 8, mean Otis *Beta Test* score 99.

Results

Closures effected under the four viewing conditions, in the order in which these latter occurred, are shown in Table II. The analysis of variance attributable to *item groups, viewing conditions, order,* and *interactions* revealed no significant differences except for the fourth condition, negative after-images, where performance was notably (0.001 level) poorer.

TABLE II

Number of Closures Effected Using Four Groups of Twelve Items under Four Viewing Conditions

Presentation	Viewing conditions				Total
	Positive without flicker	Positive with flicker	Negatives prior to positives without flicker	Negative after-image with flicker	
First	94	110	93	52	349
Second	108	93	90	73	364
Third	99	91	93	88	371
Fourth	89	121	118	57	385
Total	390	415	394	270	1469
Total possible	576	576	576	576	2304

Experiment III

The aim was to ascertain whether closure performance would be significantly better with negative after-images induced under flickering light than without.

Method

The testing situation was the standard one. The test items were 24 closure faces randomly sorted into 3 groups of 8. There were three conditions for viewing the negative after-images: without flickering light, with flickering light, with light and sound flickering synchronously.

A $3 \times 3 \times 3$ factorial design was employed, accounting for the variables *item groups*, *viewing conditions*, and *order*. This, replicated three times, called for 27 Ss.

Subjects were young undergraduates—16 men and 11 women—with a mean age of 20 years.

In addition to scoring for the number of correct closures, *E* secured the following readings: for the 27 subjects, the duration in seconds of each negative after-image from the instant *S* switched his gaze from the projecting to the viewing screen until *S* judged that the after-image was gone (employing a subjectively determined criterion as to its final useless or vanished state); for the last 18 subjects, in addition, the time in seconds from the instant of switching the gaze until the moment closure occurred. In all instances closures were described after the negative after-images were gone.

Results

The number of closures effected under the three viewing conditions is shown in Table III. The performance under flickering light is 50 per cent higher than that under steady light; and there is no difference between the conditions of flickering light and flickering light with synchronous sound.

Table IV, showing the mean duration in seconds for all negative after-images, reveals no significant variation attributable to the different viewing conditions. (It is to be noted here that the negative after-images did not appear under steady light until some five to seven seconds after

TABLE III

Number of Closures Effected With Negative After-Images Using Three Groups of Eight Items under Three Different Viewing Conditions ($N=27$)

	Viewing conditions			
Presentation	Steady light	Flickering light	Flickering light & sound	Total
First	33	45	45	123
Second	33	51	55	139
Third	43	58	51	152
Total	109	154	151	414
Total possible	216	216	216	648

switching the gaze to the viewing screen, while under flicker they appeared at once.)

Table V shows, for 18 subjects, the mean time elapsing before closure occurred. Under steady light this was ten seconds, as compared with five seconds under the conditions of flicker.

TABLE IV

MEAN DURATIONS IN SECONDS FOR NEGATIVE AFTER-IMAGES INDUCED UNDER THREE DIFFERENT VIEWING CONDITIONS ($N=27$)

	Viewing conditions			
Closure items	Steady light	Flickering light	Flickering light & sound	Total
Perceived	40.4	34.9	37.4	37.3
Not perceived	33.1	33.3	33.9	33.4
Total	36.8	34.4	36.3	35.8

TABLE V

MEAN CLOSURE TIME IN SECONDS USING THREE GROUPS OF EIGHT ITEMS UNDER THREE DIFFERENT VIEWING CONDITIONS ($N=18$)

	Viewing conditions			
Presentation	Steady light	Flickering light	Flickering light & sound	Total
First	11.0	4.8	5.8	6.6
Second	10.6	4.6	6.0	6.7
Third	8.4	5.2	3.8	5.5
Total	9.8	4.9	5.1	6.2

DISCUSSION

The purpose was to establish the validity of the method of eliciting closures with negative after-images under flickering light. There was no attempt at exact resolution of the many questions inevitably associated with the induction and enhancement of after-images by flickering light. Such questions await special study in their own right.

The exploratory investigations into perceptual closure envisaged in this study and in future studies are intended to reveal factors that may essentially facilitate or inhibit the occurrence of closure, nullifying for the time being the factor of individual differences. Such investigations entail multi-factor analysis of variance designs, and the use of standardized test materials and procedures throughout.

It was legitimate, therefore, on the basis of Experiment I, to settle on a

flicker rate of three cycles per second as approximately optimal in enhancing negative after-images in subsequent experiments. Indirect assurance that this was reasonable was independently provided by Miles' (1) unique work on the formation of "projected visual images by intermittent retinal stimulation."

The findings in Experiment II permit the conclusion that flicker had no contributory value, in itself, in the making of closures; and that the prior viewing of the photographic negatives, as prelude to induction of the negative after-images, conferred no perceptual advantage.

Experiment III leaves no doubt about the facilitatory value of flickering light during the viewing stage in effecting closures with negative after-images. Only half as much time was required to effect the closures, and 50 per cent more closures were effected, when flickering light was substituted for steady light.

In sum, with the present materials, and under the prescribed experimental conditions, perceptual closure is facilitated when the negative after-images are induced under light flickering at about three cycles per second; and the inductive procedures do not appear to have any independently invalidating effects on the closure performance. The result is a practical experimental technique uniquely suited to the present kind of closure study, in that (in contrast to the methods of direct inspection and tachistoscopic viewing) ample time is afforded for viewing the test item with but a single, fixed point of regard.

Summary

A method of eliciting closures was wanted which afforded lengthy periods of time for viewing test items with but a single fixed point of regard, and which eliminated any possibility of searching eye-movements or successive visual fixations.

A feasible method entailed the use of incomplete black and white representations of the heads and faces of real people and their presentation in the form of negative after-images induced under flickering light.

Three experiments were performed to determine optimal conditions for inducing closure in this fashion and to establish the validity of the technique.

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EFFECT OF BACKGROUND ON THE CRITICAL FLICKER FREQUENCY[1]

P. J. FOLEY
Defence Research Medical Laboratories, Toronto

ALTHOUGH the effects of variations in background on visual intensity discrimination (4, 7) and acuity (2) have been investigated, nothing has been reported of their effects on critical flicker frequency (CFF). Studies concerning the effect of stimulating one part of the retina on the CFF of another part have appeared (e.g., 5, 6, 8), but have been oriented towards the study of retinal interaction, using CFF as a measure of retinal events.

EXPERIMENT I

Apparatus

The apparatus used for producing flicker, a square wave generator activating a glow modulator tube, was based on a design given by Fritze and Simonson (3). The glow modulator, when maximum current is passing through it, emits a mixed white light having a continuous spectrum with a maximum at 510 millimicrons. It responds almost instantly to changes in current flow so that it may be regarded as producing square wave flicker.

The apparatus had four frequency ranges giving continuously variable flicker from 5 to 120 cps. For details concerning calibration see Ogilvie (9).

The light-dark ratio was set at 50:50.

The glow modulator tube was mounted in a housing and shone through a flashed opal disc, masked by the backgrounds to provide a square test patch 0.5° in width at a distance of one metre from the subject's eye.

The brightness of the patch was measured using the Spectra Brightness Spot Meter. It was found to be 135 ml. (2.13 log ml.).

Five background sizes were used, subtending 1°, 2°, 4°, 8°, and 16° at the subject's eye. In addition, the condition of a completely dark background was tested as a control. These backgrounds were produced by inserting appropriate apertures at one end of a black box. The subject looked through the other end of this box, using an eyepiece of the type found on the Hecht-Shlaer Adaptometer, in which was inserted a 2 mm. artificial pupil. The box was impervious to light and contained baffles to eliminate stray reflections. The immediate background of the flicker target was constructed of white Bristol board, and had a square aperture in its centre.

This immediate background was illuminated by a projector situated to one side of the box. Three illumination levels were used, controlled by neutral density filters in front of the projector lens. These levels gave background brightnesses of 1.13 log ml.,

[1]Defence Research Medical Laboratories Report No. 178–1, Project No. D77–94–20–26 (H.R. No. 131).

2.13 log ml., and 3.13 log ml., respectively. Thus background brightness was either equal to target brightness, or greater or less than it by one log unit.

Procedure

A modified form of the method of limits was used to measure CFF. The target was always presented first as a steady source. The frequency was then decreased at a rate of one scale division per second, corresponding to 0.15 cps/sec., until the subject reported flicker. This frequency was recorded. Three such readings were taken for each condition for each subject. Precautions were taken to ensure that subjects were not using a time criterion.

All determinations of CFF were monocular, the subject using his preferred eye. The experiments were carried out in a dark room.

Subjects

Four subjects were used, three male and one female. Their ages ranged from 27 to 35 years. None wore glasses.

Experimental Design

The three conditions of background brightness, and the six conditions of background size plus control were combined to give a 3×6 analysis of variance. To avoid the lengthy experimental sessions which would result from the subject having to pre-adapt to random background brightnesses within one session, a split plot design was used (1). This entailed three sessions per subject, one for each brightness. Background brightness was thus confounded with sessions, but since the important variable was background size, and the use of the split plot design enabled this to be measured with greater precision, the loss was considered justifiable.

The order in which the three background brightnesses were presented to each subject was random, as was the order in which the different sizes of background were presented within each session.

In an experiment of this nature, where three consecutive readings are taken within a very short time interval, the within subjects variance is likely to be very small. Therefore, in order to obtain a more appropriate error term, the entire experiment was repeated once under identical conditions, three months later. The analysis is based on the two replications.

Results[2]

Table I shows the mean values for the two replications. The results of the analysis of variance are shown in Table II. It should be noted that two error terms are used in the analysis. The first one is the triple interaction of replications, background brightness and subjects. This is the appropriate term for testing these three effects and their interactions because they can only be analysed over the whole experiment. The second error term is the sum of the residual interactions with replications. This is the appropriate term for testing the effects of background size and its interactions, i.e., the effects within one session. As was explained earlier

[2]The author wishes gratefully to acknowledge the work of Mrs. Anglin of these laboratories, who carried out the statistical analysis of the results of this experiment.

TABLE I

MEAN VALUES OF CFF IN CPS FOR THE TWO REPLICATIONS OF EXPERIMENT 1

	Size of background						
	Control	1°	2°	4°	8°	16°	
Background brightness							Overall average
I_1	25.74	27.18	27.30	27.68	27.96	28.27	27.35
I_2	25.80	27.89	28.86	29.56	29.96	30.42	28.75
I_3	25.63	26.14	26.90	27.71	27.73	27.83	26.99
Overall average	25.72	27.06	27.69	28.32	28.55	28.84	

TABLE II

SUMMARY OF ANALYSIS OF VARIANCE OF EXPERIMENT I

Source	*df*	M.S.	*F.*
R (Replications)	1	1112.2972	152.30*
I (Background brightness)			
I_1-I_3	1	9.6434	—
$I_1+I_3-2I_2$	1	238.0770	32.60*
S (Subjects)	3	168.5119	23.07*
R×I	2	14.9884	—
R×S	3	147.8664	20.25*
I×S	6	13.9624	—
R×I×S (Error)	6	7.3033	
B (Background size)			
0 vs (1°, 2°, 4°, 8°, 16°)	1	337.4644	200.32*
Linear (1°, 2°, 4°, 8°, 16°)	1	139.6737	82.91*
Quadratic	1	5.6131	—
Cubic	1	.0207	—
Quartic	1	.7905	—
I×B	10	6.1187	3.63*
S×B	15	1.7870	—
R×B	5	2.7818	—
S×I×B	30	1.8844	—
Within subjects	288	.1203	
Error	55	1.6846	
Total	431		

*$P < .01$

this gives much greater precision to the testing of the background effects, and is one of the advantages of using a split plot design. The within subjects variance was not the appropriate error term here because of the nature of the measurements involved, as was explained earlier. It can be seen from Table II that it is very small.

The differences among the various sizes of background are significant ($P<.01$). The orthogonal breakdown shows the source of variation. CFF under the control condition is significantly lower than CFF under the other conditions of varied background sizes. Therefore the presence of an

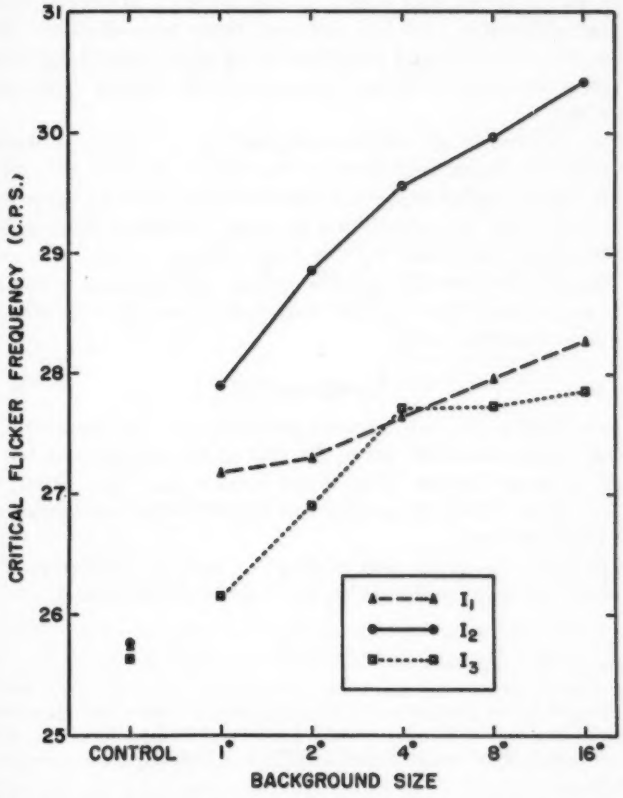

FIGURE 1. Effect of increasing background size on CFF where background brightness equals: (*a*) target brightness (I_2); (*b*) target brightness +1 log unit (I_1); (*c*) target brightness −1 log unit (I_3).

effective background will raise CFF. In addition the linear component is significant ($P<.01$), so that as one increases the size of the background, up to 16°, the CFF will also increase linearly.

There is a significant interaction between background brightness and size of background. When background brightness is equal to target brightness, CFF increases more quickly for increasing background size than it does when background brightness is greater than or less than target brightness by one log unit.

Comparing the three background brightnesses, there is no significant difference between a brightness that is greater than target brightness by one log unit, and one that is less by one log unit. However, there is a significant difference ($P<.01$) between these two situations and the situation where background brightness is equal to target brightness. The latter gives consistently higher values of CFF. Figure 1 shows these relationships.

Subject differences are of course significant ($P<.01$). However, the only significant subject interaction is that with replication ($P<.01$). The determination of flicker requires a subjective judgment on the part of the subject, and hence the establishing of some criterion if these judgments are to be consistent. When a fairly long interval occurs between judgments the criterion may change. The within subjects error in this experiment is very small, showing that during any one experimental session their criteria remained stable.

Experiment II

Fry and Bartley (4), in their work with Intensity Discrimination, stated that their results were due, not to the area of the background, but to the effect of its outer border. They stated further that "the activity which spreads from one border to another can be blocked by interposing a third border between them."

The present experiment was carried out to test whether their hypotheses could account for the results obtained in Experiment 1.

Apparatus

The flicker target appeared as a 0.5° square on a 16° background. Five displays were used in all. On four of them, black square frames, recessed so that they would not be affected by the background illuminating source, were placed concentric with the target square, and at distances of 0.5°, 1°, 2°, and 4° from its centre. The black frames subtended 10′ of visual angle in width. The fifth display was the plain 16° background.

Procedure

The same three background brightnesses were used as in the previous experiment. Measurements of CFF with each of the five presentations were made during three

sessions, one for each background brightness. The rest of the procedure was exactly as before. The same four subjects were used.

Results

Results are shown in Figure 2. It can be seen that the presence of a border has no effect on the CFF of a target appearing on a 16° background, under the three conditions of background brightness tested.

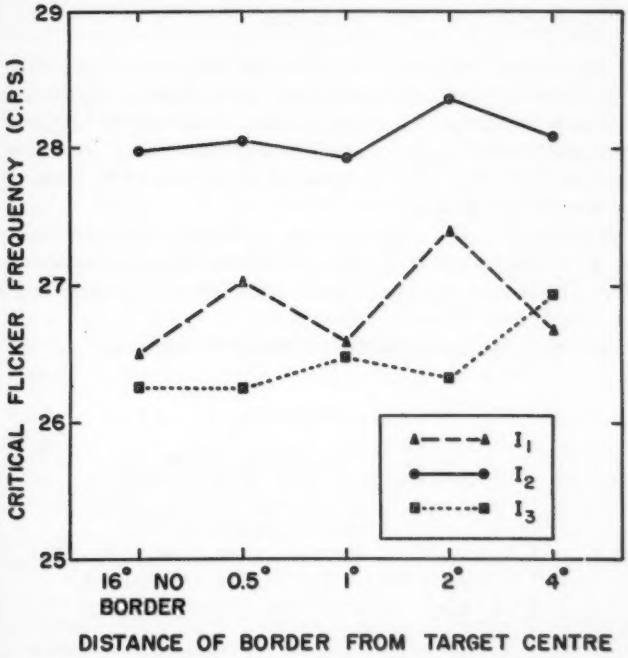

Figure 2. Effect of a border at various distances from a target upon the CFF of that target, under three conditions of background brightness.

Discussion

If the results of the second experiment had been similar to those of the first experiment, one would have been compelled to conclude either that the distance of the edge of the background from the target affected CFF, or that the presence of a border on a background affected CFF. Further, the latter alternative could be due either to the prevention of the spread

of activity from the outer border to the inner, or to the confining of any areal effects to the area within the intermediate border.

Since the results show no differences between the 16° background alone and the 16° backgrounds with frames at different distances from the target, we can only conclude that border has no effect, and that it is the area of the total background which affects CFF. Fry and Bartley's hypotheses based on intensity discrimination cannot therefore be generalized to CFF.

Summary

Two experiments were carried out to investigate (*a*) the effect of increasing background size on the CFF of a concentric target under three conditions of background brightness: such that target brightness was equal to background brightness, or less or greater than it by one log unit; (*b*) the possibility that the effect could be attributed to border phenomena rather than to area.

It was shown that as background size increases, CFF increases linearly with it. This effect is greatest when background brightness equals target brightness. There is a significant interaction between background brightness and background size.

The results cannot be attributed to border phenomena.

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THE INTERACTION OF AUDITORY FLUTTER AND CFF: THE EFFECT OF BRIGHTNESS[1]

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It has been shown that auditory flutter of the same frequency as visual flicker will affect critical flicker frequency (CFF), the CFF being higher when the flutter is in phase than when it is out of phase (5).

Similar results have been obtained with binocular flicker (1). The CFF with the flicker stimuli in phase is higher than when they are out of phase. It is not clear, however, whether the difference between in-phase and out-of-phase CFF varies with frequency. Perrin (6) has found that the difference increases with frequency, but Thomas (7) was unable to confirm these results.

In the original experiment with auditory flutter, the differences in CFF due to the phase of the flutter were not found to vary significantly with luminance, but the range of luminance was not large. In the present experiment the range was extended to three log units. Information was also obtained on the reproducibility of the interaction effect.

Apparatus

The apparatus has been described in detail elsewhere (5). Square wave flicker was obtained from a glow modulator tube (R1131C) driven by a square wave generator. The generator triggered an electronic switch which interrupted a random noise signal, thus producing auditory flutter which could be either in phase or out of phase with the flicker stimulus.

A Hecht-Shlaer adaptometer (2) was used to present the visual stimulus. The normal light source was replaced by the glow modulator tube which had in front of it flashed opal glass so that the effective size of the source was larger than the exit pupil of the adaptometer. The luminance of the stimulus was calibrated against the standard provided with the adaptometer. Luminance was varied by means of neutral density filters. Three levels of luminance were used, 1.65, 0.22 and $\bar{2}.68$ log mL. The angular size of the visual stimulus was 5 degrees and it was viewed monocularly.

The intensity of the auditory stimulus was 90 db re 0.0002 dyne/sq.cm. The subject wore ear phones with ear caps throughout the session. A DPST switch controlled presentation of the visual and auditory stimuli.

Procedure

Considerable difficulty was encountered in preliminary experiments because of the effects of the order of presentation. The first reading of CFF tended to be higher

[1]Defence Research Medical Laboratories Report No. 178–2, Project No. D77–94–20–26 (H.R. No. 139).

than subsequent ones. This effect appears to be similar to that found by Kravkov (3). He noted that CFF was changed by the introduction of an auditory stimulus but that there was rapid adaptation.

In the present experiment frequent rest periods were found necessary; without them the S's responses became extremely erratic. Five readings were obtained for each experimental condition, but the first one was treated as a practice run and ignored. At least 60 seconds rest was allowed between each set of readings.

A one-sided method of limits was used, working from fusion to flicker. The approximate CFF having been established, the frequency was decreased at a constant rate of approximately 0.15 cps/sec. until the S responded verbally that he could see flicker. The starting point of frequency was varied so that exposure to stimulus varied between 5 and 15 seconds.

The five subjects were drawn from the laboratory staff; all but one had had previous experience with flicker discrimination. They used the preferred eye throughout. They were given a five-minute rest at the middle of the session. The subjects were instructed to use central vision; this was particularly important with the lowest luminance since any attempt to scan the light patch give highly variable readings. At this luminance, peripheral viewing gives a higher CFF than central viewing.

Experimental Design

The experimental variables are summarized below:

1. Luminance
   - b_1 1.165 log mL
   - b_2 0.22 log mL
   - b_3 $\bar{2}$.68 log mL
2. Noise patterns
   - n_1 in-phase auditory flutter
   - n_2 out-of-phase auditory flutter

Readings for both noise patterns were taken at any given brightness before moving to the next level. The design therefore was a split plot, the first split being for luminance and the second for noise pattern. The levels of luminance were given in random order, and then repeated with the restriction that each level should combine with the alternate order of presentation of noise patterns. The order effects seen in the preliminary experiments would, if present, inflate the interactions with replications of the noise pattern comparisons.

The split plot design was chosen so that variability of CFF in time would affect the noise pattern comparisons as little as possible.

Results

The CFFs for each S averaged over the two replications are given in Table I. An analysis of variance was performed on the CFFs and is presented in Table II.

TABLE I

MEAN CFFs IN CPS. OF 5 SUBJECTS AT 3 LUMINANCES WITH AUDITORY FLUTTER IN AND OUT OF PHASE[1]

Subjects	Luminance					
	1.65 log mL		0.22 log mL		$\bar{2}$.68 log mL	
	Auditory flutter					
	In phase	Out of phase	In phase	Out of phase	In phase	Out of phase
1	50.85	50.27	34.59	34.40	17.20	17.06
2	52.45	52.26	37.59	37.59	18.77	18.66
3	47.13	46.91	32.17	32.06	16.67	16.53
4	45.96	45.55	32.20	32.04	16.37	16.32
5	47.57	47.53	33.76	33.68	17.81	17.60
Mean	48.79	48.50	34.06	33.95	17.36	17.23

[1]Each CFF is based on 8 readings.

TABLE II

ANALYSIS OF VARIANCE OF CFFs IN CPS

Source	df	Sum of squares	Mean squares
Replications (R)	1	10.5294	10.5924
Subjects (S)	4	706.6947	176.6737
Brightness (B)	2	39362.8563	19681.4281
B×S	8	149.9909	18.7488
B×R	2	0.8899	0.4450
S×R	4	34.8944	8.7236
B×S×R	8	26.7424	3.3428
Noise pattern (N)	1	1.8673	1.8673*
N×B	2	0.3844	0.1922
N×S	4	0.3357	0.0839
N×B×S	8	0.5031	0.0629
N×R	1	0.0115	0.0115
N×B×R	2	0.0974	0.0487
N×S×R	4	0.4325	0.1081
N×B×S×R	8	1.0431	0.1304
Error within cells	180	14.5898	0.0811
Total	239	40311.8628	

*Significant at the 1 per cent level.

When auditory flutter is in phase with visual flicker the CFF is 0.18 cps. higher than when the flutter is out of phase, and this difference is significant at the 1 per cent level. None of the interactions of the noise pattern comparison with the other variables was significant.

Inspection of the data revealed no consistent pattern in the effects of auditory flutter at the three levels of luminance. There was considerable variability both between and within subjects.

Since the interactions involving N and replications were not large in comparison with error, it was concluded that the experimental procedure used had successfully eliminated the effect of the order of presentation of the two noise patterns.

Discussion

The effect of auditory flutter on CFF was not found to vary significantly with the luminance of the visual stimulus. That such variation with luminance may occur is not ruled out by the present experiment. The standard error of a single CFF value based on four readings was 0.14 cps., which compares favourably with other experiments on CFF (4). However the differences due to the phase of the auditory flutter, although consistently in one direction, are relatively small; so that comparisons amongst these differences, without a considerable increase in experimental precision, are unlikely to be revealing.

In a previous experiment with auditory flutter and CFF, the flicker stimulus subtended 30 minutes of arc and was viewed binocularly (5). In the present experiment where the stimulus size was increased to 5 degrees and monocular vision was used, similar results were obtained. It may be concluded that the sensory interaction demonstrated does not depend on binocular viewing.

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GRADIENTS OF OUTLINE CONVERGENCE AND DISTORTION AS STIMULI FOR SLANT[1]

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In an earlier study (3), outline distortion produced by the retinal projection of a slanted circle yielded a more accurate percept of slant than outline convergence produced by a slanted rectangle. These data, however, may reflect a practice effect from the circle to the rectangle, and only one angle of slant (40°) was employed. The present experiment represents an attempt to determine differences in perceptual error for the two kinds of forms at several angles of slant with practice randomized. The conceptual framework, Gibson's theory of psychophysical correspondence (5), and the arrangements for making it operational, have already been described (1, 2, 3). The main requirement is that all but retinal cues for slant be eliminated.

The most noticeable changes in the retinal images of figures rotated about an axis in the frontal plane are those of outline shape and retinal area stimulated. With reference to shape, if the assertion that circles are simpler than rectangles, means, in Koffka's terms (8, p. 225), *internally better structured* or *in more stable equilibrium*, slanted circles should show greater resistance to the tendency to be perceived as oriented towards the frontal plane. The percept of a circle, in comparison with that of a rectangle, should be more like the retinal image than the real object. In traditional terms, the poorer shape constancy of the rectangle should result in less accurate percepts of slant. However, it may also be argued, on the basis of orthodox cue theory of depth perception, that the slant of rectangles should be perceived *more* accurately because of the more outstanding changes in perspective that occur. The corresponding changes in the retinal images of slanted circles are harder to describe.

The changes that occur under these conditions in the retinal area stimulated are easier to specify than those of shape, and also easier to order to the hypothetical effects on the visual cortex. In this study, the range of visual angles was about 4° to 10°, involving from slightly more of the retina than the fovea and the macula to more peripheral areas containing many rods as well as cones (but not the extreme periphery

[1]This study was supported by a grant from the Defence Research Board, Canada (Project DRB 9401-03).

where there is marked curvature). The illumination was well above the photopic threshold. On the basis of what is known about differential retinal acuity, as a figure is rotated out of the frontal plane, accuracy of perceiving should increase generally as a straight-line function of the angle of slant and curve in the direction of relatively greater accuracy for the foveal region. Perhaps an additional prediction may be made. Köhler and Wallach's (**10**) use of the satiation theory to explain displacement in the figural after-effect involves the assumption that satiation is greater in the peripheral than in the foveal cortex. If this is true, figures slanted at small angles from the frontal plane should tend more to be displaced outward, and thus appear flatter, than steeply slanted figures. The result of these two influences would be an S-shaped curve of accuracy of perceiving slant.

Method

The essential parts of the apparatus were as follows: a head-rest and an eyepiece permitting only monocular vision, a neutral grey reduction screen, 32.8 cm. from the observer, with a circular viewing aperture, 11.7 cm. in diameter, fitted with a shutter to conceal the stimuli between trials, and a homogeneous background in the frontal plane, 175 cm. along the optic axis from *O*'s eye. The shutter solenoid was controlled by an electronic timer accurate within 2 per cent. The stimuli were exposed 12 cm. in front of the background centred in the visual field. The *O*s recorded their percepts by setting a pointer on an ungraduated circular dial on the table in front of the head-rest. The pointer was coupled with a similar pointer on a graduated dial on *E*'s side of the reduction screen.

The four stimulus conditions, A, B, C, and D, were, respectively: a white rectangle and a white circle against a black background; and a black rectangle and a black circle against a white background. The rectangles were 28×15.4 cm. and were exposed with the long axis horizontal. The circles were 23.4 cm. in diameter, i.e., of approximately the same area as the rectangles. There were six angles of slant, 0°, 10°, 20°, 30°, 40°, and 50°.

The room illumination was indirect, centred behind the background screen, was drawn from the A.C. mains through a voltage regulator, and was decreased by a potentiometer below the point at which there were any observable irregularities on the stimulus surfaces. Non-reflecting black cloth screens were used to control the reflection from the surfaces of the room and eliminate gradients of illumination from the stimulus surfaces. The brightness of the white stimulus surfaces and the white ground was 6.5 footlamberts, measured by a Luckiesh-Taylor Brightness Meter.

The observers were eight college students, each of whom viewed all conditions at each angle of inclination with the dominant eye. The orders of conditions were randomized as follows: Observers 1 and 3, A, B, C, D; *O*s 2 and 4, B, A, D, C; *O*s 5 and 7, D, C, B, A; *O*s 6 and 8, C, D, A, B. Thirty-two different orders of the six angles of slant were taken from a table of random numbers and assigned to the 32 observer-condition combinations. Each *O* made four observations at each angle of slant in the order of four complete runs through the particular random order of angles assigned to him, but with the random interpolation of 15 other angles of slant to prevent set-formation. The responses to these angles were recorded but not used in the

analysis. Duration of exposure was 3 seconds with a 5-second interval between exposures and a 30-second rest between conditions. An introspective report was obtained after each session.

Results

In common with the results of the previous experiments (1, 2, 3), the mean perceived slants (Table I) were much less than the objective slants. For all conditions, all the differences between the mean perceived slants, taking the angles in pairs, were significant at the level of 5 per cent or better. The *t* ratios of Table II are based on the combined means for the similar figures, the combination being effected for further analysis. The comparable *t* ratios for the single conditions (not shown) are also significant at the level of 5 per cent or better.

TABLE I

Mean Perceived Slant*

Stimulus condition	Actual slant					
	0°	10°	20°	30°	40°	50°
A	.09	2.06	5.13	9.77	13.29	21.00
B	.21	1.01	4.91	10.22	16.73	27.53
C	.45	3.23	7.15	11.07	15.44	22.78
D	.00	2.56	6.44	12.69	21.56	30.00

*Each mean is based on 32 observations.

TABLE II

Significance of Mean Differences in Perceived Slant for Combined Conditions by Pairs of Angles of Slant

($df = 7$)

Comparison	Rectangles (A + C) *t*	Circles (B + D) *t*	White forms (A + B) *t*	Black forms (C + D) *t*
0°–10°	2.63*	2.11*	2.80*	3.19*
10°–20°	7.70**	4.86**	5.43**	6.32**
20°–30°	6.33**	4.34**	4.28**	5.59**
30°–40°	4.79**	7.99**	7.77**	6.45**
40°–50°	5.07**	4.32**	4.36**	5.27**

Note. The mean percepts for 0° actual slant are insignificantly different from zero.

*Significant at less than the 5 per cent level.

**Significant at less than the 1 per cent level.

For each condition, the percentage error in perception, i.e., the difference between the actual and perceived slants expressed as a percentage of the actual slant, decreased regularly as the angle of slant increased for angles greater than zero (Table III), indicating a consistent trend towards increasing accuracy of perception as the angle subtended at the eye by the stimulus decreased. That this is not a simple function, however, is suggested by the data of Table I and Figure 1. The slant of the rectangles was perceived more accurately than that of the circles at the smaller angles of slant up to a point between 20° and 30°, while the

TABLE III

PERCENTAGE ERROR IN PERCEPTION

Stimulus condition	Actual slant				
	10°	20°	30°	40°	50°
A	79.4	74.4	67.4	66.8	58.0
B	88.9	75.5	66.0	58.2	46.2
C	67.7	64.3	63.1	61.4	54.4
D	74.4	67.8	57.7	46.1	40.0

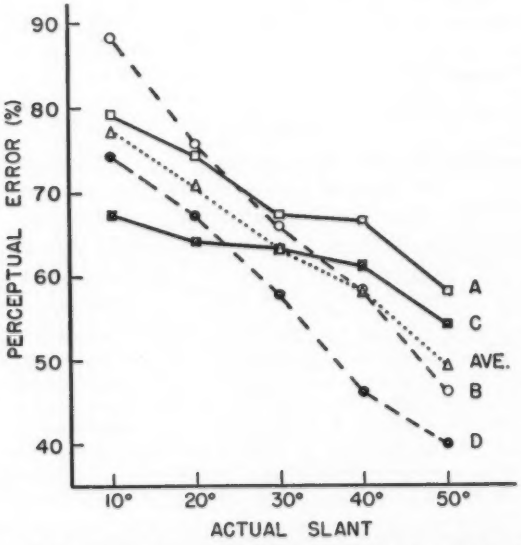

FIGURE 1. Percentage error in perception as a function of actual slant.

circles were perceived more accurately at the larger angles of slant. However, only the differences between the combined mean percepts for the similar figures at 40° and 50° are statistically significant (Table IV). Two of the curves (B and C) exhibit the predicted S-shape but the consolidated curve is generally linear with a slight tendency to curve for 50° slant. Only at 10° slant was the difference between the combined means for the white figures and the black figures significant, although all the means for the latter are larger.

The introspective reports were too qualitative to yield anything of value for the analysis.

TABLE IV

SIGNIFICANCE OF MEAN DIFFERENCES IN PERCEIVED SLANT BETWEEN COMBINED CONDITIONS AT EACH ANGLE OF SLANT ($df = 7$)

Comparison	Actual slant											
	0°		10°		20°		30°		40°		50°	
	t	p	t	p	t	p	t	p	t	p	t	p
Rectangles and circles	.55	.60	1.41	.20	.48	$>.60$	1.16	$>.30$	3.41	$<.02$	3.34	$<.02$
White forms and black forms	1.19	$>.20$	2.60	$<.05$	2.03	$>.05$	.94	$>.40$	1.45	$>.20$	1.26	$>.20$

DISCUSSION

The criticism that the satiation theory does not conform to the anatomy of the brain (12) is not in question here. The general case that differences in electrotonus occur during pattern vision seems established (9), but there has been no attempt to correlate such changes with changes in the boundaries of perceived figures. This experiment constitutes an indirect approach to the problem. The surfaces of the stimulus forms and the ground were perfectly homogeneous, the effective stimulation issuing from the edges of the figures, so that it was possible for any hypothetical current flow in brain tissue to be directly determined by the geometry of the perceived forms. Within Gibson's conceptual framework, we do not have to cope with the problem of depth in terms of three-dimensional cortical action since the only cues for depth are held to be two-dimensional gradients of stimulation that are retinal correlates, not copies, of the external changes. That observers can perceive depth under such conditions with considerable accuracy is by now well established

(1, 2, 3). The possible advantage in regarding the cortical field as being in topological, rather than metrical, correspondence with the stimulus-object shape was recognized by Osgood and Heyer (12) but seems generally to have been neglected by critics of the satiation theory, who regard demonstration of the figural after-effect in depth as presenting special difficulty for the theory in the absence of known spatial representation of the third dimension in the cortex (11, 13).

The argument that the conditions of the experiment provide the possibility of a figural after-effect is this: each *O* made 96 observations for a total of 4¾ minutes' inspection of the figures, with 5-second intertrial intervals. All stimuli were presented the same number of times at each angle of slant with order of stimuli randomized. Hammer (7), studying the time relations in the figural after-effect, found slight displacement after five seconds of inspection with a maximum after about 60 seconds. Recovery appeared to be complete in about 90 seconds.[2]

The effect of superior foveal acuity is predominant in the data, and for three curves (A, B, and C) also appears as a tendency to curvilinearity. The failure to find the effect for shallow slants predicted by the satiation theory is not regarded as crucial in view of (*a*) the tendency for two of the curves to be S-shaped, and (*b*) the non-significant differences between the mean percepts for the rectangles and the circles at the small angles of slant, in conjunction with the suggestion that the former may have been judged more accurately.

With reference to point (*a*) above, a larger number of *O*s needs to be employed to offset the broad range of individual differences in the mean percepts and sharpen the sensitivity of the test, especially for the small angles of slant. Thus, the accuracies of judgments mediated by foveal and peripheral vision could be compared. The argument advanced in the introduction that any hypothetical satiation must produce outward displacement, or flattening, of the percepts has this much against it: as the projections of the figures cover narrower parts of the retina parafoveally, the eye can span both edges of the figures at once. Thus, satiation in this area might offset that at the periphery and result in the same or more outward displacement for steep slants. If this occurs, however, it is obscured by the effects of foveal acuity. A similar argument is evident in Osgood and Heyer's (12) objection to Köhler and Wallach's (10) assumption that peripheral retinal satiation is greater than else-

[2]Displacement of percepts of figures slanted only slightly from the frontal plane in the direction opposite to the actual slant has frequently appeared in the published and unpublished data in this series of studies, under conditions in which observer ambiguity about the actual direction of slant was guarded against by the instructions. The displacement is usually obscured by averaging the data.

where, as being incompatible with the idea of a homogeneous medium for current flow, disregarding the anatomical connections. In sum, if there is a satiation effect, we still need to determine for what parts of the retina it is maximal, and its direction of change, separately from the effects of differences in acuity correlated with retinal structure. The present method of judging slant under the conditions specified by Gibson's theory would require much revision to provide for this determination.

With reference to point (*b*) above, the superiority of perceiving circles over perceiving rectangles when only retinal cues operate now seems well established for angles of slant greater than 30°, and thus far the outcome seems congruent with Gestalt theory and, more specifically, with the invariance hypothesis. It is tempting to try to relate this outcome to the facts of differential retinal acuity, but this would be premature until the suggestion that rectangles are perceived more accurately than circles at small angles of slant has been tested under these conditions with more *O*s, and employing a circle, a square, and rectangles with varied dimensions, with their longer axes oriented both vertically and horizontally. Also, it seems reasonable at present to attribute the finding that horizontal after-effects are greater than vertical after-effects to the differential structure of the eye-muscles (12) rather than to the effect of satiation. The point, however, needs testing experimentally.

With further reference to satiation, if the slant of the livelier bright figures on dark grounds had been consistently and significantly judged with greater accuracy than the slant of the dark figures on bright grounds, and such a finding could be related to the figural after-effect, satiation might be explainable in terms of fatigue—a view that seems to have been summarily dismissed by the two leading critics of the theory (12, p. 99). In the present experiment the converse occurred, but the differences are not significant.

A different explanation, which might have been confirmed by the data, but was not, is the norm theory of Gibson and Radner (6), in accordance with which Gibson's tilted line effect (4) was ascribed to the tendency of inspected objects to deviate from vertical and horizontal norms. The theory requires that figures be judged most accurately for some intermediate angle or angles.

Summary

Eight *O*s viewed monocularly four film-forms: a white circle and a white rectangle on black grounds; a black circle and a black rectangle on white grounds. The forms were shown in the frontal plane and slanted

10°, 20°, 30°, 40°, and 50° about a vertical axis. The curve of error in judging slant was a straight-line function of the visual angle, rather than S-shaped as predicted on the basis of superior foveal acuity and peripheral cortical satiation. Circles were perceived better than rectangles at slants greater than 30° but the differences in the opposite direction for the smaller angles, though consistent, were statistically insignificant. Black figures were perceived more accurately than white ones, but these differences were also statistically insignificant.

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PACING AND PERFORMANCE ON A SERIAL ADDITION TASK[1]

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BILLS has shown (1, 2, 3, 4) that when subjects respond rapidly either verbally or manually to a homogeneous series of stimuli, over a period of time, a decrement in number of responses per minute typically occurs. The decrement is accompanied by a proportionally greater increase in blocking and length of blocks. Blocking has been defined (1) as "a pause in responses equivalent to the time of two or more average responses." Bills regarded blocks as involuntary rest periods which delayed onset of "mental fatigue" (1, 8). In these experiments the subject was permitted to work at his own pace.

Recently Conrad (6) noted a similar phenomenon using a different technique. The task was a sensory-motor one requiring anticipation of changes within a four dial display, but instead of permitting the subject to work at his own speed, he was "paced" in the sense that, though signals required for action were continuously visible, response could not affect signal speed which was controlled by the experimenter.

Conrad found that blocks of the kind described by Bills occurred at high speeds and lasted from one to three seconds. During this time the subjects missed all action signals. Other signals were missed because of "attentional lapses" at slow speeds and "narrowing of attentional span" at high speeds. Further analysis indicated that the probability of a signal being missed also depended both upon time interval between signal and nearest response, and upon mean signal speed. To explain why proportionally more signals were missed as stimulus speed increased, Conrad makes use of the concept "speed stress," which he regards as "a general environmental stress which has a strength roughly constant if the mean signal speed is constant, and is independent of detailed changes in prevailing temporal conditions" (6).

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[3]The author wishes to acknowledge the valuable assistance of Mrs. Margaret Anglin in the analysis of the data in this study, and the courtesy of the Commanding Officer, RCAF Station, London, in making subjects available.

Additional data from his experiment (5) indicate that most signals were responded to, and mean temporal accuracy of response appeared to be constant irrespective of display changes. However, response reaction time was slow if the initiating signal followed a previous response very closely, or if the interval from one signal to the next in a series was long.

In Conrad's experiment each stimulus required for action was both continuously visible and complete. With inspection time uncontrolled, the interval between display changes appeared to constitute that significant temporal factor or pacing agent. However, there remains the problem of possible interactions between stimulus duration and interval between stimuli when each item of information required for action is incomplete. It may be that Conrad's (7) emphasis upon change rather than duration as the important factor in conceptualizing the way in which timing affects behaviour holds mainly in cases where each stimulus is a self-sufficient action signal.

The present experiment seeks information bearing upon two questions suggested by the above experiments: (1) Defining *pacing* as frequency of stimulus presentation, does level of performance vary with it, or with changes in stimulus duration? In other words, with a given frequency of presentation is there a time-on-time-off ratio effect? (2) Assuming that "on-off" effects can be demonstrated, are they independent of effects due to changes in pacing?

Method

Sixty-one digits ranging from one to nine were projected successively under experimental conditions which varied the exposure time for individual digits and the rate of presentation independently.

The subject was required to add the number before him on the screen to the one that had immediately preceded it and to call out his answer. If he made a mistake or missed a number in the series, he could cut back into the series by not responding to one number and then adding to it the next one to appear.

Apparatus

A magazine-load automatic slide projector was used. Each digit appeared on a day-view screen located on a table 45 in. from where *S* sat. The projected size of each digit was 1 in. The projector was connected to two interval timers so that the exposure time for each digit ("on" phase) and the interval between exposures ("off" phase) could be independently varied.

All stimuli were mounted singly on 2×2 glass slides.

The *S*'s responses were recorded by *E* on a prepared answer sheet on which were printed the series of stimuli and correct responses.

Subjects

The *S*s were RCAF Flight Cadets ranging in age from 18 to 24 years. All had recently been selected for aircrew training, and therefore had a minimum of Grade 12

education. Each S had taken an auditory version of the serial addition task one week prior to this experiment. In this pre-training, the stimuli were presented by means of a tape recorder, one digit every 1½ sec. The S's task was identical with that reported here, and his verbal responses were recorded.

Experiment I

Procedure

Twenty Ss were given a series of 61 digits projected successively under nine conditions. The stimuli were "on" 0.4, 0.8, and 1.2 sec., and were "off" 0.4, 0.8, and 1.2 sec., giving five frequencies of presentation composed of nine combinations of "on-off" phases. The order of presentation of the conditions was randomized for each S, and there was a two-minute rest interval following each presentation of the series. The *E* recorded the number of correct answers, the number of wrong answers, and the number of stimuli not responded to.

TABLE I

Analysis of Variance for Per Cent Correct

Source	df		SS	MS	F
Subjects (S)	19		14.3236	0.7534	17.41*
Stimulus duration (I)	2	Linear	2.5056	2.5056	57.87*
		quadratic	12.6188	12.6188	291.43*
Intervals between (O)	2	Linear	2.5931	2.5931	59.89*
		quadratic	6.1204	6.1204	141.35*
S × I	38		1.8802	0.0495	—
S × O	38		1.8141	0.0477	—
I × O	4		2.4245	0.6061	14.00*
Error	76		3.2934	0.0433	
Total	179		47.5737		

*P = .01

TABLE II

Mean Percentage of Correct Answers Given by 20 Flight Cadets on a Serial Addition Task with Various Frequencies of Presentation

	Stimulus duration ("on" phase)		
Interval between ("off" phase)	0.4 sec.	0.8 sec.	1.2 sec.
0.4 sec.	46.5	70.0	92.5
0.8 sec.	72.1	81.9	94.3
1.2 sec.	86.1	90.8	96.7

TABLE III

AVERAGE NUMBER OF SUCCESSIVE STIMULI MISSED WITH INCREASE IN PACING ON THE SERIAL ADDITION TASK

(N = 20 Flight Cadets)

	Intervals (seconds)								
"On" phase	1.2	1.2	0.8	1.2	0.4	0.8	0.4	0.8	0.4
"Off" phase	1.2	0.8	1.2	0.4	1.2	0.8	0.8	0.4	0.4
Secs/digit	2.4	2.0	2.0	1.6	1.6	1.6	1.2	1.2	0.8
Means	0.69	0.86	0.91	1.02	1.07	1.31	1.62	1.65	2.52

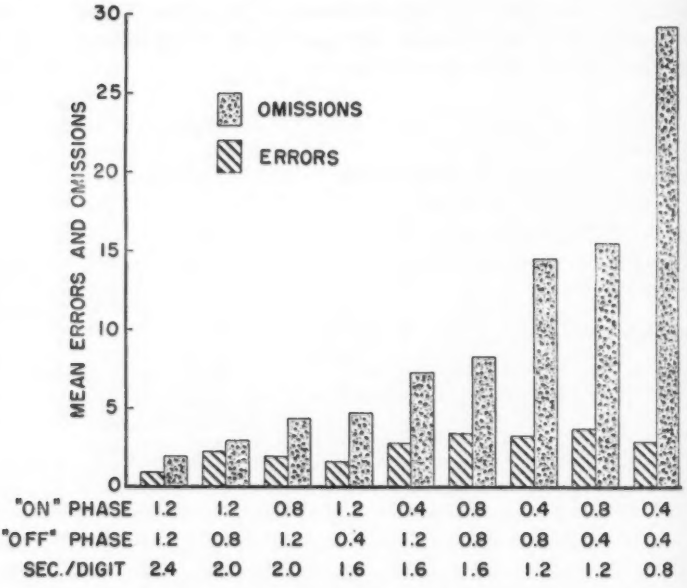

FIGURE 1. Frequency of errors and omissions by 20 Flight Cadets on a paced serial additional task.

Results

The principal findings are shown in Tables I, II, III, and Figure 1.

(1) Table I summarizes an analysis of variance of percentage of items correct. The first point of note in this table is that the subject interactions are not significant. Though there were significant differences between Ss

in level of performance, their reactions to the nine conditions of testing were consistent.

(2) A significant interaction between "on" and "off" phases is also shown in Table I, and illustrated in detail in Table II, where the data are expressed as percentage correct. From Table II it can be seen that with increase in pacing from one stimulus every 2.4 sec. to one every 0.8 sec. there is a significant decrease in percentage correct, but that this decrease in percentage correct depends also on the "on-off" ratio.

(3) In the diagonal of Table II may be seen three conditions where the frequency of presentation is 1.6 sec., but where the on-off ratios are 0.4 to 1.2, 0.8 to 0.8, and 1.2 to 0.4 sec., respectively. The percentage correct under each condition is different, and these differences are all significant. The condition in which the ratio is 1.2 to 0.4 sec. is the easiest; the opposite ratio (0.4 to 1.2 sec.) is intermediate in difficulty; and the 50:50 on-off ratio (0.8 to 0.8 sec.) is the most difficult. The tendency for the larger on to off ratio to yield higher scores is also evident when frequency of presentation is 2.0 sec. (Table II: combinations of 1.2 and 0.8 sec.), but not when it is 1.2 sec.

(4) Figure 1 shows an increase in frequency of omissions with increased pacing similar to that reported by Conrad (6). This increase is disproportionately high when compared with the increase in frequency of errors.

(5) Table III shows a tendency towards an increase in the average number of successive omissions with increase in pacing. This may be analogous to the similar increase in blocks reported by Bills as associated with increases in length of work period under self-paced conditions.

Experiment II

Procedure

This experiment was carried out to test the generality of the trends suggested in section (3) of the above results. The task in this case was identical with that used in Experiment I except that the 9 test conditions consisted of combinations of "on" intervals of 0.3, 0.6, and 0.9 sec., and "off" intervals of 0.3, 0.6, and 0.9 sec. Again the order of presentation of conditions was randomized for each S. Subjects were seven Flight Cadets from the same recruiting intake as those used in Experiment I.

Results

The principal findings are summarized in Tables IV and V. The results of this experiment support those of Experiment I in such detail that elaborate analysis seemed unwarranted. It will be noted that with a slightly different ratio an "on-off" effect, similar to that for frequency of

1.6 sec. in Experiment I, is now shown for the 1.2 sec. pacing. In Experiment I, it will be recalled, no "on-off" effect was demonstrated for this frequency. Again the 50:50 ratio is the most difficult. And there is again an increase in omissions with increase in pacing.

TABLE IV

MEAN PERCENTAGE OF CORRECT ANSWERS GIVEN BY 7 FLIGHT CADETS ON A SERIAL ADDITION TASK WITH VARIOUS FREQUENCIES OF PRESENTATION

	Stimulus duration ("on" phase)		
Interval between ("off" phase)	0.3 sec.	0.6 sec.	0.9 sec.
0.3 sec.	34.3	54.1	76.9
0.6 sec.	53.1	67.6	81.2
0.9 sec.	72.9	79.8	88.3

TABLE V

AVERAGE NUMBER OF SUCCESSIVE STIMULI MISSED WITH INCREASE IN PACING ON THE SERIAL ADDITION TASK

(N = 7 Flight Cadets)

	Intervals (seconds)								
"On" phase	0.9	0.9	0.6	0.6	0.3	0.6	0.6	0.3	0.3
"Off" phase	0.9	0.6	0.9	0.3	0.9	0.6	0.3	0.6	0.3
Secs/digit	1.8	1.5	1.5	1.2	1.2	1.2	0.9	0.9	0.6
Means	1.03	1.41	1.33	2.00	2.08	1.74	2.24	2.37	3.45

DISCUSSION AND CONCLUSIONS

(1) The present results show that the level of performance on the paced serial addition task depends not only on frequency of stimulus presentation but also upon the time-on-time-off ratio.

Of particular interest in this connection is the fact that in both experiments a 50:50 on-off ratio resulted in the poorest performance, as compared with other on-off ratios within the same pacing interval. This indicates that certain on-off effects may be independent of particular frequencies of presentation.

(2) The disproportionate increase in omissions with increase in pacing, as compared with increase in wrong answers, agrees with Conrad's results on a sensory-motor task.

(3) It should be noted that, under the conditions of this study, subjects tend to block rather than to give wrong answers with increased pacing.

(4) Finally, the results of the experiments reported here suggest that it is not sufficient to conceptualize the effects of timing on behaviour in terms of frequency of presentation alone.

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EFFECT OF ANTI-THYROID THERAPY ON OBJECTIVE-TEST PERFORMANCE[1]

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In recent years there has been a growing interest among endocrinologists and psychologists in the relation between endocrine disorders and human behaviour. Clinical observations suggest that both endocrine deficits and excesses may be associated with changes in "temperament" (3). Cushing's syndrome in adults is frequently associated with characteristic depressive states, and in Addison's disease apathy and lack of initiative are apparent. Other syndromes such as hypopanpituitarism, male and female climacteric, and thyroid imbalance are also characterized by "temperament" changes. With appropriate endocrine therapy, these clinical signs usually lessen or disappear. While there is an abundance of hormone studies on animals (1), and clinical reports of human patients (e.g., 6), there are hardly any human experimental studies of the relation between hormonal variations and those aspects of personality that are clinically described as "temperament." Apart from their intrinsic interest, such studies should aid in defining some significant dimensions of temperament in terms of objective procedures or tests, and this in turn should aid more refined studies of the relation between hormone balance and human temperament. The present study is the first investigation in a general programme to determine if systematic variations in objective and quantifiable psychological measures parallel variations in hormone balance.

There are relatively few patients with endocrine disturbances serious enough for them to seek treatment at an endocrine clinic. The most frequent patient at such clinics is the hyperthyroid. (Over a two-year period, the experimenter was able to obtain experimental data from 36 such patients.) Hyperthyroid patients are described clinically as hyperactive, tense, irritable, and excited, with a diminution of these signs after adequate anti-thyroid therapy. It is the relation between these aspects of behaviour and thyroid function that is the concern of this study. Specifically, it deals with the effect of anti-thyroid therapy on the performance of hyperthyroid patients in certain experimental tasks. The tasks employed were: *speed of tapping, auditory reaction-time, visual reaction-*

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time, time estimation, and *leg-lift persistence.* These tasks were selected to reflect changes in rapidity of action, speed of response, estimation of time, and fatigability which are often ascribed to hyperthyroid patients in clinical reports. The general plan of the study involved comparing the performance on these tasks (*a*) of hyperthyroid patients before and after antithyroid therapy, and (*b*) of hyperthyroid patients and a group of control subjects.

Method

Subjects

The experimental or hyperthyroid group consisted of 36 out-patients of the endocrine clinics in two general hospitals who had been diagnosed as hyperthyroid by a group of endocrinologists in clinical conferences. Of the patients 26 were female, ranging in age from 19 to 62; and 10 were male, ranging in age from 17 to 57. Control data were collected from two other groups: (*a*) 32 patient-controls from the general-medical and surgical clinics, under treatment for a variety of ailments but with no known hormone imbalance; this group was matched in age-range and male-female ratio with the group of hyperthyroid patients; and (*b*) 96 normal-controls from a Royal Canadian Air Force training school and the introductory psychology course at McGill University.

Experimental tasks

1. *Speed of tapping.* The apparatus, adapted from Eysenck (4), consisted of a telegraph key, on which was mounted a holder for a 5 × 8 inch index card. The key was wired through a battery to a counter which recorded the number of key depressions. Subjects were instructed to poise a sharp-pointed pencil over the centre of the card in a standardized position, at a given signal to start tapping the pencil on the card as rapidly as possible, and to stop on another signal. Score on this task was the number of taps in a ten-second period.

2. *Reaction time.* For this task, a simple reaction-time apparatus was used, with a white light and a red light as visual stimuli, and a buzzer as auditory stimulus. The subject was instructed to keep both hands on the table, one on each side of the apparatus, and to respond to the stimulus with his right hand as quickly as possible. The right hand, rather than the "preferred" hand, was used, as other investigators indicate no significant difference in the two techniques (7). Subjects were given a "ready" signal two seconds before the onset of the appropriate stimulus. There were ten practice trials with one light, followed by five test trials with the same light as the stimulus; then five practice trials with the buzzer and five test trials with the buzzer; and finally five test trials with the other light. Score on this task was the time between the onset of the stimulus and completion of the reaction.

3. *Time estimation.* The methods of both estimation and reproduction, as described by Bindra and Waksberg (2), were used. A light stimulus of 15 seconds' duration was used as the standard for both estimation and reproduction. Subjects were required to estimate the duration of the standard stimulus once, then presented with the standard again and asked to reproduce the standard interval. Twelve reproductions represented one trial, and the score obtained was the mean time for the twelve reproductions. Data obtained with the method of estimation showed great variability, and only the reproduction data are presented.

4. *Leg-lift persistence.* The subject was seated facing a chair of the same height as that on which he was seated, with his right leg extended, so that his heel rested on

the second chair. He was then asked to raise his leg to the level of a six-inch ruler, and to keep it in this position as long as possible. Trial ended when heel touched the chair again. Score was the mean time in seconds for two trials, in the case of normal-controls, and time in seconds for one trial in the case of the two patient groups.

Procedure

The experimental tasks were pre-tested on the 96 normal-control subjects, and basic reliability data collected.

Hyperthyroid patients performed the tasks in the clinic before the onset of antithyroid therapy and again when they had recovered. The time between the two testing periods varied between two and six months. Data on patient-controls were also obtained in the clinic. The tasks were administered in the order in which they are listed above.

Results

With the exception of the anticipated high correlation between visual and auditory reaction times (Pearson $r = .936$) scores on the experimental tasks (for the 96 normal-controls) were uncorrelated, i.e., measures of speed of tapping, reaction time, time estimation and leg-lift persistence appeared to be independent. Test-retest reliability (Pearson r) for 32 normal-controls, given the tasks in the same order as the patients, was as follows: speed of tapping, 0.820; visual reaction time, 0.781; auditory reaction time, 0.772; time estimation, 0.721; and leg-lift persistence, 0.383.

In testing the null hypothesis that the performance on experimental tasks of hyperthyroids before and after therapy did not differ significantly, two-tailed t values were calculated, using the formula for correlated means (5); in making all other comparisons the formula for independent means was used.

Table I shows the mean scores of hyperthyroid patients before and after antithyroid therapy. Significant differences appeared on all the experimental tasks. Before therapy the patients were slower in speed of tapping, had longer reaction times, grossly overestimated elapsed time, and had shorter leg-lift persistence times than after therapy. The changes in performance after therapy were all in the direction of the means for

TABLE I

Mean Performance of Hyperthyroids Before and After Therapy ($N = 36$)

	Before therapy	After therapy	t	p
Speed of tapping (taps in 10 seconds)	32.50	51.40	4.50	.001
Auditory reaction time (seconds)	.56	.36	3.67	.001
Visual reaction time (seconds)	.77	.38	7.52	.001
Time estimation (seconds)	8.70	16.60	2.75	.01
Leg-lift persistence (seconds)	14.40	27.00	2.83	.01

TABLE II

MEAN PERFORMANCES OF HYPERTHYROIDS BEFORE THERAPY AND OF PATIENT-CONTROLS

	Hyperthyroids before therapy ($N = 36$)	Patient-controls ($N = 32$)	t	p
Speed of tapping (taps in 10 seconds)	32.50	50.40	3.96	.001
Auditory reaction time (seconds)	.56	.40	2.84	.01
Visual reaction time (seconds)	.77	.46	5.82	.001
Time estimation (seconds)	8.70	21.60	3.88	.001
Leg-lift persistence (seconds)	14.40	13.10	.42	n.s.

TABLE III

MEAN PERFORMANCES OF PATIENT-CONTROLS AND NORMAL-CONTROLS

	Patient-controls ($N = 32$)	Normal controls ($N = 96$)	t	p
Speed of tapping (taps in 10 seconds)	50.40	60.70	1.98	.05
Auditory reaction time (seconds)	.40	.35	1.65	n.s
Visual reaction time (seconds)	.46	.41	1.54	n.s.
Time estimation (seconds)	21.60	18.60	1.20	n.s.
Leg-lift persistence (seconds)	13.10	46.10	9.61	.001

the normal-control group (see Table III). Twelve of the normal-controls who were retested six months after original testing, a period corresponding to the recovery period of the hyperthyroid group, showed no significant change in their performance from test to retest.

Table II compares the performance of hyperthyroids before therapy with that of patient-controls. Significant differences existed between the two groups on four of the measures, the differences being in the same direction as those between normal-controls and hyperthyroids. The only measure on which there was no difference between hyperthyroids and patient-controls was the score on leg-lift persistence.

Table III compares the performances of the patient-controls and normal-controls. Normal-controls had significantly higher scores on leg-lift persistence, and tended to be more rapid in tapping. Reaction-time and time estimation measures were not significantly different.

DISCUSSION

Since the performance of hyperthyroids showed a significant change following anti-thyroid therapy, and the change was in the direction of the data for the normal group, it appears that the treatment given to the hyperthyroid patients somehow brought about the change in test performance. The question arises, however, as to whether these changes are ascribable to the mere fact of general recovery from illness or can be related specifically to changes in hormone balance.

Two aspects of the data support the latter interpretation. First, measures for patient-controls on auditory reaction time, visual reaction time, and time estimation were not significantly different from those of the normal-control group. This result is not compatible with the interpretation that these measures are affected by *any* kind of illness. Secondly, patient-controls and hyperthyroids before therapy differed significantly on four of the five measures. This differential performance could not be expected if the measures were equally affected by hyperthyroidism and by the variety of illnesses represented in the patient-control group. The only task on which the performance of these two groups did not differ was the leg-lift persistence. It is possible that this test of fatigability is affected by general state of health. However, its reliability is too low to permit any definite statements.

The data of this introductory study suggest, therefore, that speed of tapping, auditory reaction time, visual reaction time, and time estimation measures are sensitive to variations in thyroid balance, and might well be used in further experimental studies of the relation between thyroid-hormone imbalance and changes in the activity, speed, and "pep" aspects of temperament.

Summary

Thirty-six hyperthyroid patients were compared before and after anti-thyroid therapy with 32 patient-controls and 96 normal-controls on the following tasks: speed of tapping, auditory reaction time, visual reaction time, time estimation, and leg-lift persistence. Measures on all five tasks for hyperthyroid patients showed significant changes after anti-thyroid therapy; the changes were in the direction of the data for the normal-controls. Hyperthyroids before therapy also differed significantly from the patient-controls in the two reaction-time and the time estimation measures. The differences and changes in test performance are interpreted as reflecting variations in hormone balance rather than a general-illness syndrome.

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PHYSIOLOGICAL GRADIENTS AS INDICANTS OF "AROUSAL" IN MIRROR TRACING[1]

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ELECTROMYOGRAPHIC (EMG) gradients have been the subject of a number of experiments in our laboratory (1, 2, 13, 15, 16). On the basis of data relating gradient steepness to performance scores in mirror tracing and to reported interest in a listening situation, Bartoshuk hypothesized that the slope of some EMG gradients is indicative of "motivation to do the task" (2, p. 216). Surwillo provided experimental evidence for this hypothesis by demonstrating that steepness of EMG gradients varied with degree of incentive (15). The present experiment was designed to determine whether gradients of the kind found with EMGs could also be obtained with physiological functions under autonomic control, such as heart rate, blood pressure, and respiration.

The above statements relate our problem to "motivation"; however, like Duffy (4, 5, 6) and others, we regard this concept as standing in need of revision. As Duffy has pointed out (6), motivation has at least two major components, intensity and direction, the former of which urgently requires study. Just as quantitative study of vision really began with the analysis of visual experience into attributes, so, we suggest, the identification of an intensitive dimension in behaviour should lead to progress in the quantification of data on action, work, fatigue, and personality. What we propose is a kind of psychophysics of action, in which physiological measurement replaces instruments for measuring physical intensity (radiometer, photoelectric cell, etc.) and objective measures of performance take the place of introspective judgment. In such a context "just noticeable difference," for instance, would be defined in terms of the increase in level of physiological activity required to produce a significant change in level of performance. Following Freeman (8, p. 100) and Hebb (9), we will use the term "arousal" to designate this general intensitive

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dimension of behaviour. (N.B. We are not using this term to refer to the EEG phenomenon called "arousal" or "activation.")

Method

Subjects[3]

Subjects were 43 male personnel of the Royal Canadian Air Force, with age range 17 to 35, and mean age 22.2 years. All were screened by a psychiatric interview. For two left-handed Ss appropriate adjustments in apparatus were made.

Procedure

Mirror tracing. The task was to trace the outline of a circle four times in succession, while viewing the paper in a mirror which reversed the vertical dimension but did not affect the horizontal. Apparatus, instructions, and other procedure were essentially those employed by Bartoshuk (2), except that there were four traversals per trial in the present experiment and only one in Bartoshuk's. The longer trials were in order to observe changes in the slower autonomic functions. The subject was instructed to count his traversals of the circle, and to stop after the fourth time around.

Physiological recording. Electromyograms (EMGs) from forehead, right-forearm extensors, and right-forearm flexors were recorded on an Offner electroencephalograph, and integrated tracings (two-per-second rate) were recorded on a separate Edin chart drive (3). A third chart drive recorded a pneumographic tracing of respiration and a continuous tracing of heart rate, provided by an Edin electrocardiotachometer. Finally, a fourth chart drive recorded a continuous tracing of systolic blood pressure by means of the Cambridge Blood Pressure Recorder (12). The blood pressure cuff was placed on the left arm of all Ss except the two left-handed ones, and was deflated between trials (in lengthy trials, also at the mid-point) to reduce discomfort. One channel on each chart drive was used for a marker pen which indicated onset and termination of trials and rest periods, and also, by a photocell device described by Bartoshuk (2, p. 216), signalled S's traversal of each successive octant of the circle.

Experimental conditions. For general procedural details, see 2, p. 217. In the present experiment there were eight trials, with approximately three minutes' rest between trials. Physiological recordings commenced 30 seconds before each trial and were continued 30 seconds after it ended. During the approximately two minutes when no recording was made, the paper was changed in the mirror-tracing apparatus. The examiner watched S during tracing, and stopped him if he continued longer than four times around the circle. To control for postural artifacts, S began each successive trial in a different quadrant of the circle.

Treatment of Data

EMG. Measurements of integrator spikes were made as follows. First, the even-numbered octants (i.e., quadrants) of distance traversed were marked. Next, the two spikes of each side of the signal marker were measured with a rule calibrated in microvolts, and the average value entered on the data sheet. This operation was repeated 16 times for each trial. In plotting group curves, data were separately combined for first four and last four trials. In plotting gradients, Bartoshuk's method was used (2, p. 219).

[3]We express our deep gratitude to the men of the R.C.A.F. who served as subjects, and to the officers who assisted with arrangements.

For correlational analysis, values of "gradient steepness" were computed for each S. All data were fractionated for the first four and the last four trials. Because of an atypical downward dip in the final quarter of curves, data for the fourth traversal were omitted in computing gradient steepness.[4] Gradient steepness was expressed as a ratio (see **2, p. 219**).

Data from the tracings of heart rate, blood pressure, and respiration were similarly analysed. Measurements of heart rate were 8, instead of 16 as in the case of EMG. For blood pressure, the entire performance time was divided into four equal parts. For respiration there were only two values: (*a*) for the first circle and half of the second; (*b*) for the other half of the second and the third.

Results

Figure 1 presents graphs for EMG, heart rate, and blood pressure, showing a rise (through the first three traversals) in all cases. The graphs were plotted from data for trials 5–8. Those for trials 1–4 were similar, as were the graphs for forehead-muscle tension, except that the latter yielded a less regular gradient than those shown. Note in Figure 1 how the last quarter of each curve flattens out or declines.

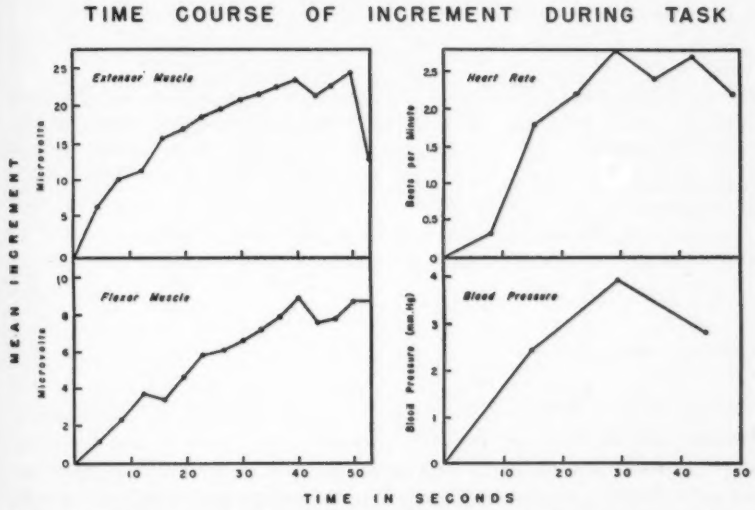

Figure 1. Vincent curves for four physiological functions showing progressive rise in level of physiological activity during the first three-fourths of the task.

[4]We suspect that the atypical flattening of our curves on the fourth traversal is an artifact due to our subjects' being instructed to count their traversals and stop after the fourth. In previous work with mirror drawing, subjects traversed the circle only once; the additional responsibility placed on our subjects may have distracted their attention from the task. The point is to be checked in a later experiment.

TABLE I

MAGNITUDE AND RELIABILITY OF PHYSIOLOGICAL GRADIENTS

Physiological variable	Trials	Mean steepness* of gradient	C.R.	P
Extensor muscle	1–4	.49	3.93	>.001
	5–8	.70	4.49	<.0001
Flexor muscle	1–4	.17	5.08	<.0001
	5–8	.19	3.19	<.01
Forehead muscle	1–4	.04	2.55	.01
	5–8	.02	1.22	.23
Heart rate	1–4	.05	3.72	<.001
	5–8	.07	4.47	<.0001
Blood pressure	1–4	.10	7.08	<.0001
	5–8	.15	8.56	<.0001
Respiration	1–4	.0001	1.05	.29
	5–8	.0004	2.53	<.02

*N = 43 for all functions except forehead muscle and respiration, where N = 40.

TABLE II

INTERCORRELATIONS AMONG MEASURES OF GRADIENT STEEPNESS (N = 43)

Physiological variable		Ext. 5–8	Flex. 1–4	Flex. 5–8	Heart rate 1–4	Heart rate 5–8	Blood press. 1–4	Blood press. 5–8
Extensor muscle	(1–4)	.86	.62	.46	.13	.24	.30	.52
" "	(5–8)		.38	.44	.12	.32	.26	.55
Flexor muscle	(1–4)			.67	.02	.26	.05	.34
" "	(5–8)				−.01	.47	−.17	.35
Heart Rate	(1–4)					.53	.25	.35
" "	(5–8)						−.18	.20
Blood pressure	(1–4)							.42

Table I gives the mean steepness of gradient for each physiological function and the reliability of its difference from zero. It will be noted that right-forearm muscles, heart rate, and blood pressure yielded extremely reliable gradients. Those for respiration and forehead muscle were less reliable, but each yielded one significant gradient.

Table II presents product-moment correlation coefficients, based on an N of 43. The table shows statistically reliable correlations in gradient steepness between skeletal muscles and the two autonomic measures: heart rate and blood pressure. In general, trials 5–8 yielded higher correlations than trials 1–4. Correlations between blood pressure (trials 5–8)

and forearm-extensor muscle tension were particularly high. Note that higher r's were obtained between both autonomic measures and the skeletal-muscle values than were obtained by correlating the autonomic variables with each other.

Because of the omission of cases owing to difficulties in recording, N was reduced to 40 for correlations involving respiration and forehead. Correlating these variables (fractionated for trials 1–4 and 5–8) with the others yielded no r's significant at the 0.01 level. However, six r's were significant at the 0.05 level, all involving respiration. Respiration correlated significantly once with each of the other five variables, and the sixth reliable r was one of 0.35 between trials 1–4 and 5–8 of respiration. The only reliable r for the forehead-muscle variable was 0.38 between forehead, trials 1–4, and respiration, trials 5–8. Forehead-muscle tension was the only variable failing to show a reliable correlation between trials 1–4 and 5–8.

Gradient Steepness and Performance Time

Because of the non-linearity of some of the relationships between performance time and gradients, we used non-parametric methods—Wilcoxon's test (17) or the Mann-Whitney U Test (12)—to determine reliability. In all cases performance time was the variable ranked. Table III shows five significant relationships, all in the following direction: the steeper the physiological gradient, the shorter the performance time. Blood pressure was outstanding ($P<.001$). Extensor-muscle tension and heart rate also yielded significant P values. Contrariwise, respiration, flexor-muscle and forehead-muscle tension failed to show the relationship significantly, although flexor-muscle for trials 1–4 almost reached the 0.05 level.

TABLE III

RELATIONSHIP BETWEEN GRADIENT STEEPNESS AND PERFORMANCE TIME

Physiological variable	Trials 1–4		Trials 5–8	
	*C.R.**	*P*	*C.R.*	*P*
Extensor muscle	—	$<.02$	—	$<.05$
Flexor muscle	—	$>.05$	—	—
Forehead muscle	.32	—	—	—
Heart rate	2.48	$<.02$	.61	—
Blood pressure	3.47	$<.001$	3.27	$<.001$
Respiration	—	—	—	—

**C.R.* omitted when Wilcoxon's test (17) used.

For blood pressure in trials 1–4, where the relationship was nearly linear, a product-moment correlation coefficient of — 0.52 was obtained. With N 43, this is significantly well below the 0.01 level.

Discussion

The main conclusion from the present findings is that gradients accompanying mirror-drawing performance are not confined to the skeletal-motor system. They were also clearly observed in physiological functions under autonomic control. These gradients from different physiological functions are significantly intercorrelated, suggesting that they share, at least in part, some of the same mechanisms of central-neural control. Moreover, the autonomic gradients (especially blood pressure), like forearm-extensor gradients, were significantly related to excellence of performance as measured by speed of mirror tracing. (As in Bartoshuk's findings (2, p. 224) relationships of forearm-flexor gradients to performance did not quite reach significance.)

Physiological Gradients and Motivation

Bartoshuk(2), Surwillo (15), and Stennett (14) have summarized evidence for the relationship between muscle-potential gradients and motivation. The present study adds further confirmation for muscle-potential gradients, and also demonstrates for the first time that autonomic gradients occur. The argument for regarding muscle-potential gradients as indicants of motivation may now be extended to autonomic functions such as blood pressure. However, until as much work has been done with autonomic gradients as with EMGs, we cannot draw as firm conclusions concerning their relationship to motivation and "arousal."

The Concept of Arousal

Bartoshuk's findings (2, p. 228) suggested an optimum value of gradient slope, beyond which performance did not benefit from further increase, and might be slightly impaired by what he called "excessive motivation." In this connection he refers to Hebb's concept of "arousal," a concept which seems to us preferable, at least in the present context, and which obviates the need to speak of "excessive motivation" or of "emotion." The "arousal continuum" is seen by Hebb and others—notably Freeman (8) and Duffy (6) (who, however, does not employ the term)—as a fundamental dimension of behaviour. It is defined independently of excellence of performance. Freeman (7) and Hebb (9) suggest that the relationship between these two functions (*viz.*, arousal and excellence of performance) is curvilinear, having the shape of an inverted U; and that, proceeding upward from the lower part of the arousal continuum

(sleep, drowsiness), the effect on efficiency is beneficial (performance scores rise progressively) up to a certain critical point, beyond which further increase has deleterious effects. Woodworth and Schlosberg also deal with this general question (18, pp. 176 ff.).

In a recent experiment Stennett (14) has for the first time, as far as we know, provided convincing evidence of this inverted-U curve.[5] Employing, to a considerable extent, physiological determinations (such as muscle-potential gradients) as measures of "arousal," he showed that increasing the level of arousal beyond an optimal point reduced accuracy of tracking. The finding of autonomic gradients has the practical significance that they may be used along with skeletal-muscle gradients in providing a composite measure of "arousal." The methodological value of this is suggested by the work of Lacey *et al.* (10), who found that individuals vary with respect to the physiological system which responds most markedly under stress.

It should be emphasized that "arousal" cannot replace "motivation," but may represent its "intensity" component, leaving the "direction" component (goal structuring, etc.) untouched. No general conclusion is yet justified, but present data suggest that the arousal dimension may account for a considerable share of variance in a subject's output, while leaving much variance still unaccounted for.

Summary

Previous studies from our laboratory and elsewhere suggest that EMG gradients may serve as indicants of drive or "arousal." The present study sought to determine whether similar gradients appear in autonomic functions such as heart rate and blood pressure, and, if so, whether such gradients correlate significantly with EMG gradients and with level of performance.

Forty-three subjects traced a circle viewed in a mirror. There were eight trials, each consisting of four traversals of the circle. Physiological measures recorded were: heart rate, blood pressure, respiration, EMGs from flexor and extensor muscles of the right arm, EMGs from the forehead.

All physiological functions yielded significant gradients; autonomic gradients were significantly correlated with EMG gradients; and the following physiological measures were reliably correlated with speed of performance: EMG (extensor), heart rate, and blood pressure. It was concluded that "arousal-related" gradients are not confined to the skeletal-motor system.

[5]Freeman earlier published a curve showing the U-shaped function in one subject (7).

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STIMULUS UNCERTAINTY, RESPONSE UNCERTAINTY, AND PROBLEM SOLVING[1]

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As an experimental method, the variety and uses of problem solving situations seem limited only by the ingenuity of the investigator. In its various forms, problem solving has been employed in the measurement of intelligence and the study of individual differences (**1, 4, 5, 13, 14, 15**), and in the investigation of the effects of stress on performance (**1, 2, 6, 7, 8, 9**). The process of problem solving has also been an area of investigation in its own right, and as many interpretations of problem solving have been offered as there are theorists of learning and perception. However, there has been little systematic investigation of the basic dimensions of problem solving.

Common sense and fashion suggest that an application of the Shannon-Weaver theory of communication may be useful in delineating these basic dimensions. We may, for example, imagine a situation in which the problem for the subject is to discover, by trial and error, the S-R code which assigns each of the possible stimuli to one and only one of the possible responses. If the S-R code is such that a given response may be assigned to more than one stimulus, the number of alternative stimuli and the number of response alternatives may be varied independently of each other. Shannon (**12**) has defined a subject's uncertainty as $\log_2 n$, where n is the number of equiprobable alternatives from which one is to be drawn. In the experimental situation just described, stimulus uncertainty is defined by $\log_2$ of the number of equiprobable stimuli, of which only one is presented at a time. Similarly, the response uncertainty is defined by $\log_2$ of the number of equiprobable alternative responses, from which one is preselected by the experimenter to be the "correct" response for each stimulus. Thus, in this situation, an S-R code is employed, but is unknown to the subject, and stimulus and response uncertainty are independently manipulable.

The Shannon-Weaver theory is useful in so far as it suggests this

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CANAD. J. PSYCHOL., 1956, **10** (4).

relatively simple and pure form of the problem solving situation and eliminates the variability and low generality of findings from problem solving experiments where substantive content is involved. There are serious limitations to the application of the information model to human behaviour, since it was designed to describe the properties of inanimate communication channels. However, it may provide a reasonably adequate model for describing the problem solving process. It does provide a method of statistically analysing non-metric data.

The present experiment employs an experimental situation like the one described, in an effort to investigate the effects of stimulus and response uncertainty on problem solving behaviour.

Method

Apparatus

From S's point of view, the apparatus consisted of a wooden box, the front panel of which is schematically represented in Figure 1. On the right side of the panel was an array of buttons, each of which was individually removable. To the left of the buttons a red pilot light was mounted. This served as an indicator of the occurrence of a "correct" response. To the left of the red light was a white screen behind which was mounted a small loudspeaker for delivering auditory stimuli. Directly above the speaker opening was a white pilot light which served as a signal, warning S of the imminent onset of the stimulus. In addition to this panel, three Hunter timers, an audio oscillator, and a chronoscope were employed.

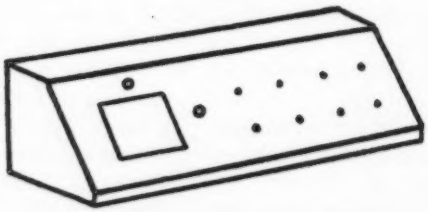

Figure 1. Schematic drawing of apparatus.

Procedure

A trial consisted of a fixed sequence of three time intervals which were controlled and repeated by the Hunter timers. The first interval was 2 sec. in duration, during which the white light was illuminated. At the end of the 2 sec., the light was extinguished. Simultaneously with this event the second interval, which lasted for 5 sec., was begun. At the onset of this interval, the chronoscope was started and a tone was presented. The chronoscope was stopped and the tone terminated by pushing any one of the available buttons. Pushing the "correct" button illuminated the red light for the remaining portion of the 5-sec. interval. If no response was made, the tone and the chronoscope remained on until the end of the 5-sec. period. The buttons were activated only during this period and a latching relay circuit prevented the

occurrence of more than one response during a given trial. Simultaneously with the end of the 5-sec. interval, the third time period began. This interval lasted for 10 sec., during which the apparatus was inactivated to allow time for *E* to record the observations and to make the necessary adjustments for the next trial. At the end of the 10-sec. period the cycle was repeated, starting with the presentation of the 2-sec. warning signal. Total time per cycle was therefore 17 sec.

Experimental design

Table I provides a diagram of the experimental design. Four groups of 28 Ss each were presented with problems having either 1, 2, 3, or 4 tones. Thus the rows of Table I represent independent groups. Each of these groups received three problems, with 4, 6, and 8 buttons in counterbalanced order.[3] The columns of the table, therefore, represent dependent subgroups.

TABLE I

EXPERIMENTAL DESIGN

No. of tones	No. of *Ss*	No. of response alternatives		
		4	6	8
1	28			
2	28			
3	28			
4	28			

Subjects and Instructions

The Ss were 112 male and female McGill University students enrolled in an elementary psychology course. After assuring the Ss that the experiment was not a test of their intelligence or personality, they were instructed as follows:

"This is an experiment in guessing behavior, and it goes something like this. When this white light comes on you are to get ready to respond. Shortly after that, the light will go off and you will hear a tone of a given pitch. Your problem is to guess which one of these buttons is the correct one for the (each) tone. You simply indicate your guess on each trial by pushing the button which you think is going to be the correct one. If your guess is correct, the tone goes off and this red light comes on. If your guess is incorrect, the tone goes off as before, but that's all for that trial. You are permitted, then, just one guess on each trial, but we shall continue running trials in each experiment until you have found the correct button for the (each) tone.

"Now, I determine in advance which button is the correct one for the (each) tone. That is, I don't change anything while you are working on the problem. Thus this

[3]The groups with 1 and 2 tones also received additional problems with 2 buttons. These data are not included in this report since the groups having 3 and 4 tones did not receive problems with 2 buttons. The order in which the problems were presented appeared to have little or no effect on performance.

all boils down to an initial shot in the dark, but then becomes a problem in elimination. There is only one correct button for the (each) tone, but a given button may be the correct one for more than one tone. . . .[4] Since I am interested in your reaction time, would you try to make your guess on each trial as quickly as you can, but don't knock yourself out over it."

In order to obtain stable latency measures, preliminary trials were run during which the S-R code was provided for S. These data, of course, provide an empirical measure of the subjective stimulus uncertainty. During both the preliminary and the actual problem solving trials, the order of occurrence of the tones, in the three groups where more than one tone was employed, followed a fixed scrambled order which assured equal probabilities of occurrence. The "correct" buttons were selected in a similar manner, so that the frequencies with which each button was the "correct" one were roughly equal. The tones employed in this experiment had the following frequencies: 200, 400, 2,000, and 4,000 cps. When only one tone was used, it was the 200 cps. tone. The group with two tones received the 200 and 400 cps. tones, and so on.

On each trial, the latency of response, measured from the onset of the tone, and S's choice among the available buttons were recorded.

Results

Tables II presents the mean trial number of the first correct response for each group. The cell entries in this table were obtained by computing the mean for all tones for each S, and then obtaining the mean for all Ss. This method was employed since we view the problem presented to the 8 group having four tones and eight buttons, for example, as a two bit choice followed by a three bit choice. We deal with the average response uncertainty of three bits rather than with the sum of the four response uncertainties, twelve bits. This follows from the fact that in this case $4 \times 8 = 32$ alternative responses at the outset are reduced to $4 \times 1 = 4$ at solution, a reduction equivalent to three binary choices or bits.

The data presented in this table indicate that the mean trial number of the first correct response is a direct function of both stimulus uncer-

TABLE II
MEAN TRIAL NO. OF FIRST CORRECT RESPONSE

No. of tones	No. of response alternatives		
	4	6	8
1	2.4	3.4	5.4
2	2.7	3.4	5.0
3	3.0	3.8	5.4
4	3.3	4.4	6.1

[4]This usually required amplification. When necessary, the instruction was repeated and an example where more than one tone was assigned to a given button was described.

tainty and response uncertainty. Analysis of variance indicates that both of these main effects are significant well beyond the 0.01 level; interaction between them is negligible. In order to determine the relative effectiveness of each variable, the partial regression equation for this measure as a function of $H(x)$ and $H(y)$ (stimulus and response uncertainty, respectively) was computed. This partial regression equation is as follows: Trial of first CR $= -.353 + .124\,H(x) + .253\,H(y)$. The two regression coefficients are significantly greater than zero, but not different from each other, indicating that both stimulus and response uncertainty have a significant and roughly equal effect on the trial number of the first correct response.

Table III presents the mean number of repetition errors made before the first correct response. A repetition error is defined as a choice of an incorrect button after the first choice of that button. Again, the means presented in the table are across tones and subjects. The frequency of repetition errors is found to be directly related to both stimulus and response uncertainty. Analysis of variance on these data indicates that both main effects are significant beyond the 0.01 level, and again there are no interaction effects. The partial regression equation is as follows: R.E. $= -1.070 + .550\,H(x) + .432\,H(y)$. Again, the regression coefficients are greater than zero but not different from each other.

TABLE III

MEAN NO. OF REPETITION ERRORS BEFORE THE FIRST CORRECT RESPONSE

No. of tones	No. of response alternatives		
	4	6	8
1	0.0	0.0	0.5
2	0.1	0.3	0.6
3	0.4	0.6	0.8
4	0.9	1.0	2.0

Analysing these data with the aid of information statistics requires that we view response uncertainty, $H(y)$, as the input and $H(z)$, based on the distribution of responses, as the output of the communication channel. $T(y;z) = H(y) + H(z) - H(y,z)$ is the amount of transmitted information, and this quantity is computed for successive trials. As a function of trials, $T(y;z)$ begins roughly at 0 and increases to $H(y)$ at the limit, at which time all Ss have solved the problem. As response uncertainty varies from group to group, so the asymptotic value of $T(y;z)$

varies from group to group. The quantity $D(z{:}y) = T(y{:}z)/H(y)$ is an expression for the exhaustiveness of transmission, or the relative amount of $H(y)$ transmitted on a given trial. This measure takes on values between 0 and 1; 0 before the first trial, and 1 on whatever trial solution is reached by all members of the group. The slope, b, of this line over the first ten trials per tone in each group is presented in Table IV. A large number indicates a relatively high rate of information transmission per trial; a small number indicates a relatively low rate of assimilation of the available information per trial. Analysis of variance on these data indicates that both stimulus and response uncertainty bear a significant inverse relationship to the rate of transmission per trial. The partial regression equation follows: $b = .281 - .048\ H(x) - .047\ H(y)$. Again, both coefficients are significantly different from zero but not from each other.

Turning to the latency data, Table V presents the mean latency over all trials for each of the groups. Latency of response is directly and significantly related to stimulus uncertainty, but the similar, more tenuous, relationship between latency and response uncertainty is not significant. The partial regression equation also expresses this:

$$\mathrm{RT} = .616 + .275\ H(x) + .026\ H(y).$$

TABLE IV

SLOPE (b) OF $D(z{:}y)$ VS TRIALS

No. of tones	No. of response alternatives		
	4	6	8
1	0.240	0.176	0.090
2	0.175	0.103	0.076
3	0.110	0.095	0.078
4	0.085	0.064	0.036

TABLE V

MEAN LATENCY OVER ALL TRIALS

No. of tones	No. of response alternatives		
	4	6	8
1	0.687	0.689	0.769
2	0.872	0.878	0.890
3	1.093	1.069	1.135
4	1.241	1.271	1.278

Bricker and others (3) have defined the rate of gain of information $\dot{T} = 1/b$, where b is the slope of the regression line relating transmitted information to reaction time. $\dot{T}$ is expressed in units of bits per sec. In the present experiment, we have two measures of the rate of gain of information, $\dot{T}_x = 1/.275 = 3.64$ bits per sec., and $\dot{T}_y = 1/.026 = 38.46$ bits per sec.

Discussion

In problem solving, as in test construction and scaling, the usual measure of difficulty is in terms of the proportion of Ss failing a test or test item. Use of percentage scores requires rather large samples if relatively small effects are to be measured. Miller (10), Rogers and Green (11), and others have made considerable progress in establishing the sampling distributions of information measures. Even with small samples, the expected variance of uncertainty measures is rather small. It is felt that while the usual measure of difficulty is satisfactory for many purposes and has the advantage of simplicity, the measures of information employed here have the advantage of greater stability and sensitivity, in addition to providing a model for describing the process of problem solving itself. The use of these measures has the further advantage of permitting a meaningful combination of both time and error scores, for example, rate of gain of information.

From the point of view of problem solving, the present experiment indicates that both stimulus and response uncertainty are important variables for controlling problem solving behaviour. The majority of experiments in the literature have tended to ignore the response side of the picture. While manipulation of these two variables is useful for controlling problem solving behaviour, only future research can indicate whether the distinction between stimulus and response uncertainty will be useful in predicting the effects of other variables such as rewards, punishments, stress, etc., on problem solving. Preliminary data from our current research suggest that this distinction may indeed have considerable utility in making such predictions.

Experiments on disjunctive reaction time have confounded variation in stimulus uncertainty with concomitant variation in response uncertainty. The direct relation between reaction time and stimulus and/or response uncertainty was generally attributed to the effects of stimulus uncertainty. The present experiment helps confirm this interpretation of the obtained relationship. However, the value for $\dot{T}_x$ obtained in the present experiment is somewhat lower than that found in other experiments on disjunctive reaction time. Bricker (3) has reviewed these experiments and reports that in many of them $\dot{T}_x$ varies between 5.5 and 7.5 bits per sec.,

but remains relatively constant over a fairly wide range of experimental variation. However, these experiments all employed visual-spatial discriminations. The tones employed in the present experiment are certainly not as discriminable from each other as are the positions of an illuminated light. It is suggested, therefore, that in addition to stimulus uncertainty *per se*, the discriminability of stimuli may be another important variable influencing the rate of gain of information and problem solving in general. Although auditory reaction times are generally shorter than visual ones, the inequality between visual-spatial and auditory acuity probably accounts for the lower rate of gain of stimulus information obtained in the present experiment. The high rate of gain of response information we obtained also suggests that under the present conditions Ss have little difficulty in discriminating one button from the other, although they have some difficulty in remembering which buttons have been tried on previous trials.

From the point of view of ascertaining the effects of other variables, for example stress, on problem solving, the results of the present experiment provide rather clean and reliable control data. As indicated above, preliminary findings suggest that the information statistics employed here are more sensitive to the effects of stress than are the more usual measures of performance. Although they involve somewhat more labour, measures of uncertainty seem to have a utility and sensitivity which is lacking in the standard measures of trials to solution and frequency of errors.

Summary

The present experiment was concerned with the effects of variation in stimulus uncertainty and response uncertainty on problem solving. Shannon's definition of uncertainty was employed. Four groups of 28 Ss each were presented with problems having one, two, three, or four auditory stimuli, to each of which *E* had pre-assigned a "correct" response. A response consisted of pressing one of several buttons available to *S*. *S*'s problem was to find the "correct" button for each stimulus by eliminating "incorrect" buttons on successive trials. Each group of Ss received three problems, in which the "correct" responses had been selected from four, six, and eight buttons, respectively. The following results were obtained:

(1) The mean trial number of the first correct response for each stimulus is directly related to both stimulus and response uncertainty.

(2) The mean frequency of repetition errors (more than one choice of an incorrect button, for each stimulus) is also directly related to both stimulus and response uncertainty.

(3) The relative rate of gain of information per trial is an inverse function of both stimulus and response uncertainty.

(4) The rate of gain of information per sec. is directly related to stimulus uncertainty but is unaffected by response uncertainty.

These results were discussed and it was suggested that the distinction between stimulus and response uncertainty might be of some value in predicting the effects of other variables, e.g., reward, punishment, stress, on problem solving behaviour.

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OPTIMAL OPERATING CONDITIONS FOR RADAR DISPLAYS EMPLOYING MAGNESIUM FLUORIDE PHOSPHORS[1]

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IN typical radar displays, the target indication is a glowing point of light on the circular face of a cathode-ray tube (CRT). This target, or "pip," is caused by electrons striking a layer of phosphorescent material; and background brightness can be varied by varying the grid bias of the CRT.

Many commonly used radar CRTs employ a double-layer sulfide (P-7) phosphor screen. Experiments have shown (2, 4, 5) that the visibility of pips on such displays can be enhanced by the use of the appropriate grid bias and ambient illumination. Similar optima have not as yet been reported for the single-layer magnesium fluoride phosphors which are now coming into use.

Some preliminary data have been given by Tucker and Griffiths (3) for the CV429 tube, a magnesium fluoride type. Using the special conditions of a single bright line, intensity modulated in a small region, they found that the minimum threshold in volts (dV/V) was not reached until the bias became at least five volts positive with respect to visual cut-off (the bias at which the line display could just be seen in darkness).

These results are comparable to findings with the P-7 phosphor. They should, however, be extended to the case where the display is of the plan-position indicator (PPI) type; i.e., where a rotating radial "sweep-line" is caused to brighten at a point representing the position of the radar target in distance and direction. The previous work of these laboratories was done on such PPIs; and the present report is concerned with optimal conditions of bias and illumination for PPI displays employing magnesium fluoride phosphors.

APPARATUS AND METHODS

The target generating equipment, test room, and variable light source have been described (2). A CV429 tube was mounted in a "universal" radar display.[2]

[1]Defence Research Medical Laboratories Report No. 163–11, Project No. D77–94–20–22 (H.R. No. 133).

[2]The "universal" display is designed to accommodate CRTs of from 5" to 25" in diameter. The face of the tube can be set at any angle. The high voltage supply is variable from 3 to 30 kilovolts by a continuous control on the front panel; an

Visibility thresholds (in decibels of attenuation of a 45 volt reference signal) were determined under various conditions of CRT bias and ambient illumination. Four bias values and five levels of ambient illumination were used, in a factorial design. The illumination levels, measured at the centre of the display, were: Darkness (i.e., absence of any light other than the glow from the display), and 0.1, 0.5, 1.0, and 1.2 foot-candles. Bias voltages were measured from Visual Reference Intensity (VRI), i.e., the bias which yields a just-visible sweep-line to the dark-adapted eye. The three higher biases, in order of increasing sweep-line brightness, were 5, 10 and 15 volts positive from VRI. Because of changes in dark adaptation, true VRI could not be used experimentally. Instead, for those conditions where the design called for VRI, the bias was set at the smallest positive voltage which gave a just visible sweep-line with the amount of light present. VRI was, however, determined for each S prior to the experimental session.

Five Ss (four female, one male) were used. A single threshold[3] was determined for each S under each condition. A different random order of the 20 conditions was used for each S. The target appeared within a one-inch square drawn with grease pencil on the display. The display was "noise-free"; i.e., the randomly fluctuating mottled appearance of the background which is typical of operational radars was largely absent.

Results

Mean visibility thresholds are shown in Figures 1 and 2. Because of the different bias settings needed for the dimmest sweep-line, and the sharpness of the peak in the curve as compared with the range of values for any one point ($\pm$ 2.7 db), no statistical analysis was attempted.

Optimal bias for this display occurs at five volts above VRI. Ambient illumination as high as 0.5 f.c. can be tolerated without loss.

Discussion

Theoretical reasons for the existence of an optimal grid bias on radar displays have been set forth by Williams, Bartlett and King (4). For targets of the size used here (about 20 minutes of visual angle), the relationship between threshold contrast and background brightness can be determined. The background brightness of a radar display (in the absence of "noise") is a function of grid bias; and, if that function were linear, our curves of Figure 1 should closely match those given by Black-

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adjacent meter indicates the voltage. Grid bias is similarly adjusted and read, over a range of 0–100 volts. Signals are normally coupled directly to the grid of the CRT, but integral amplifiers are provided to increase signal strength where required, and to permit mixing random noise with the signal.

[3]Thresholds were determined by an abbreviated form of the method of limits. Because of phosphor persistence (which is particularly long for the CV429 display) only ascending series were employed.

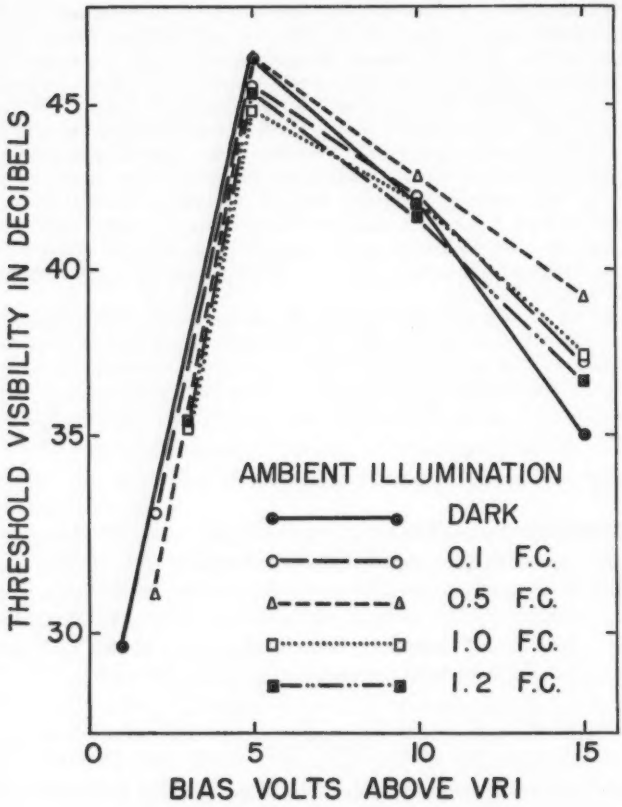

FIGURE 1. CRT bias and target visibility.

well (1). However, the relationship between bias and brightness is non-linear; the phosphor eventually reaches a point of apparent saturation, at which no increase in brightness can be obtained, no matter what bias is used. It is this non-linearity which introduces the peak in our data.

Williams *et al.* (4), working from the Blackwell data and from measured curves of bias and brightness for the P-7 display, have shown that their results fit this explanation. Equivalent data are not yet available for the CV429. When these are obtained, it is expected that a similar correspondence can be established.

Higher light intensities can be tolerated for the CV429 than for tubes of

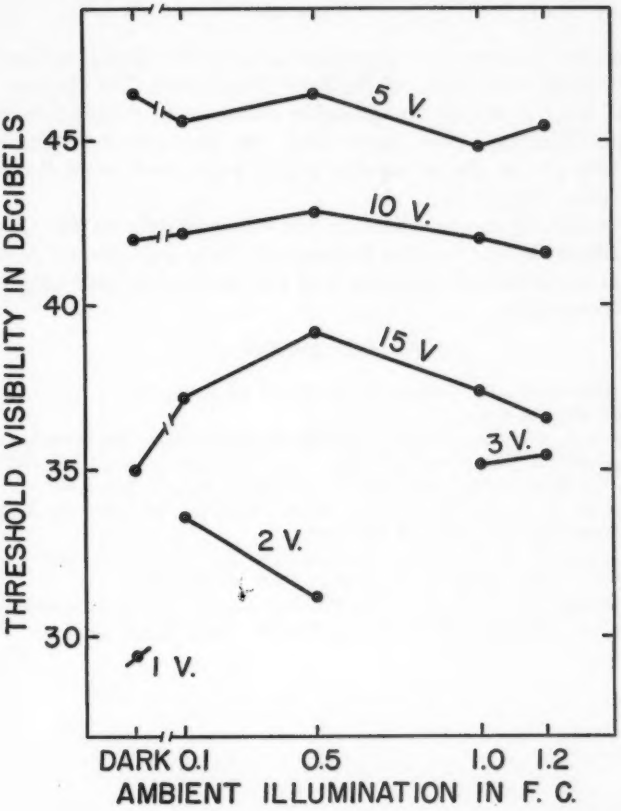

FIGURE 2. Ambient illumination and target visibility.

the P-7 type. Williams and Hanes (5) have suggested that ambient illumination should not exceed the brightness of the display in the region just behind the sweep-line (about 0.1 e.f.c. for the P-7 at optimal bias); and it is possible that the CV429 display is correspondingly brighter. Confirmation of this suggestion awaits the establishment of the bias-brightness function for the magnesium fluoride phosphor.

Again, the P-7 display is rather easily excited to phosphorescence by visible light; the CV429 is not. The difference between the two displays may then reflect the differing responses of the two phosphors to ambient illumination.

SUMMARY

Synthetic radar targets were observed on a PPI display under varying conditions of CRT bias and ambient illumination. The display used a CV429 tube, in which the phosphor screen is of magnesium fluoride. Minimal thresholds were found when the bias was five volts positive from VRI (where the sweep-line is just seen), and when the ambient illumination was 0.5 f.c.

These findings can be related in part to known data on the variation of the contrast threshold of the human eye, when due account is taken of the non-linear function between grid bias and background brightness of cathode-ray tubes.

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